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ANNUAL REPORT OF THE
BOARD OF REGENTS OF
THE SMITHSONIAN
INSTITUTION

SHOWING THE
OPERATIONS, EXPENDITURES, AND
CONDITION OF THE INSTITUTION
FOR THE YEAR ENDING JUNE 30

1934

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SMITHSONIAN INSTITUTION
WASHINGTON



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LETTER OF TRANSMITTAL

SMITHSONIAN INSTITUTION,
Washington, January 28, 1935.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1934. I have the honor to be,

Very respectfully, your obedient servant,

C. G. ABBOT, *Secretary.*



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ANNUAL REPORT OF THE BOARD OF REGENTS OF THE
SMITHSONIAN INSTITUTION FOR THE YEAR ENDING
JUNE 30, 1934

SUBJECTS

1. Annual report of the Secretary, giving an account of the operations and conditions of the Institution for the year ending June 30, 1934, with statistics of exchanges, etc., including the proceedings of the meetings of the Board of Regents.

2. Report of the executive committee of the Board of Regents, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1934.

3. General appendix comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1934.

THE SMITHSONIAN INSTITUTION

June 30, 1934

Presiding officer ex officio.—FRANKLIN D. ROOSEVELT, President of the United States.

Chancellor.—CHARLES EVANS HUGHES, Chief Justice of the United States.

Members of the Institution:

FRANKLIN D. ROOSEVELT, President of the United States.

JOHN N. GARNER, Vice President of the United States.

CHARLES EVANS HUGHES, Chief Justice of the United States.

CORDELL HULL, Secretary of State.

HENRY MORGENTHAU, Jr., Secretary of the Treasury.

GEORGE H. DERN, Secretary of War.

HOMER S. CUMMINGS, Attorney General.

JAMES A. FARLEY, Postmaster General.

CLAUDE A. SWANSON, Secretary of the Navy.

HAROLD L. ICKES, Secretary of the Interior.

HENRY A. WALLACE, Secretary of Agriculture.

DANIEL C. ROPER, Secretary of Commerce.

FRANCES PERKINS, Secretary of Labor.

Regents of the Institution:

CHARLES EVANS HUGHES, Chief Justice of the United States, Chancellor.

JOHN N. GARNER, Vice President of the United States.

JOSEPH T. ROBINSON, Member of the Senate.

M. M. LOGAN, Member of the Senate.

DAVID A. REED, Member of the Senate.

T. ALAN GOLDSBOROUGH, Member of the House of Representatives.

EDWARD H. CRUMP, Member of the House of Representatives.

CHARLES L. GIFFORD, Member of the House of Representatives.

IRWIN B. LAUGHLIN, citizen of Pennsylvania.

FREDERIC A. DELANO, citizen of Washington, D. C.

JOHN C. MERRIAM, citizen of Washington, D. C.

R. WALTON MOORE, citizen of Virginia.

ROBERT W. BINGHAM, citizen of Kentucky.

AUGUSTUS P. LORING, citizen of Massachusetts.

Executive committee.—FREDERIC A. DELANO, JOHN C. MERRIAM, R. WALTON MOORE.

Secretary.—CHARLES G. ABBOT.

Assistant Secretary.—ALEXANDER WETMORE.

Administrative assistant to the Secretary.—HARRY W. DORSEY.

Treasurer.—NICHOLAS W. DORSEY.

Editor.—WEBSTER P. TRUE.

Librarian.—WILLIAM L. CORBIN.

Personnel officer.—HELEN A. OLMSTED.

Property clerk.—JAMES H. HILL.

UNITED STATES NATIONAL MUSEUM

Keeper ex officio.—CHARLES G. ABBOT.

Assistant Secretary (in charge).—ALEXANDER WETMORE.

Associate Director.—JOHN E. GRAF.

SCIENTIFIC STAFF

DEPARTMENT OF ANTHROPOLOGY:

Walter Hough, head curator; W. H. Egberts, chief preparator.

Division of Ethnology: Walter Hough, curator; H. W. Krieger, curator; H. B. Collins, Jr., assistant curator; Arthur P. Rice, collaborator.

Section of Musical Instruments: Hugo Worch, custodian.

Section of Ceramics: Samuel W. Woodhouse, collaborator.

Division of Archeology: Neil M. Judd, curator; F. M. Setzler, assistant curator; R. G. Paine, aid; J. Townsend Russell, honorary assistant curator of Old World archeology.

Division of Physical Anthropology: Aleš Hrdlička, curator; Thomas D. Stewart, assistant curator.

Collaborator in anthropology: George Grant MacCurdy; D. I. Bushnell, Jr.

Associate in historic archeology: Cyrus Adler.

DEPARTMENT OF BIOLOGY:

Leonhard Stejneger, head curator; W. L. Brown, chief taxidermist.

Division of Mammals: Gerrit S. Miller, Jr., curator; Remington Kellogg, assistant curator; A. J. Poole, scientific aid; A. Brazier Howell, collaborator.

Division of Birds: Herbert Friedmann, curator; J. H. Riley, associate curator; Alexander Wetmore, custodian of alcoholic and skeleton collections; Casey A. Wood, collaborator; Arthur C. Bent, collaborator.

Division of Reptiles and Batrachians: Leonhard Stejneger, curator; Doris M. Cochran, assistant curator.

Division of Fishes: George S. Myers, assistant curator; E. D. Reid, aid.

Division of Insects: L. O. Howard, honorary curator; William Schaus, honorary assistant curator; B. Preston Clark, collaborator.

Section of Hymenoptera: S. A. Rohwer, custodian; W. M. Mann, assistant custodian; Robert A. Cushman, assistant custodian.

Section of Myriapoda: O. F. Cook, custodian.

Section of Diptera: Charles T. Greene, assistant custodian.

Section of Coleoptera: L. L. Buchanan, specialist for Casey collection.

Section of Lepidoptera: J. T. Barnes, collaborator.

Section of Orthoptera: A. N. Caudell, custodian.

Section of Hemiptera: W. L. McAtee, acting custodian.

Section of Forest Tree Beetles: A. D. Hopkins, custodian.

Division of Marine Invertebrates: Waldo L. Schmitt, curator; C. R. Shoemaker, assistant curator; James O. Maloney, aid; Mrs. Harriet Richardson Searle, collaborator; Max M. Ellis, collaborator; William H. Longley, collaborator; Maynard M. Metcalf, collaborator; Joseph A. Cushman, collaborator in foraminifera; Charles Branch Wilson, collaborator in Copepoda.

Division of Mollusks: Paul Bartsch, curator; Harald A. Rehder, assistant curator; Mary Breen, collaborator.

Section of Helminthological Collections: Maurice C. Hall, custodian.

Division of Echinoderms: Austin H. Clark, curator.

Division of Plants (National Herbarium): Frederick V. Coville, honorary curator; W. R. Maxon, associate curator; Ellsworth P. Killip, associate curator; Emery C. Leonard, assistant curator; Conrad V. Morton, aid; Egbert H. Walker, aid; John A. Stevenson, custodian of C. G. Lloyd mycological collection.

Section of Grasses: Albert S. Hitchcock, custodian.

Section of Cryptogamic Collections: O. F. Cook, assistant curator.

Section of Higher Algae: W. T. Swingle, custodian.

DEPARTMENT OF BIOLOGY—Continued.

Division of Plants—Continued.

Section of Lower Fungi: D. G. Fairchild, custodian.

Section of Diatoms: Albert Mann, custodian.

Associates in Zoology: C. Hart Merriam, W. L. Abbott, Mary J. Rathbun,
C. W. Stiles, Theodore S. Palmer, William B. Marshall.

Associate Curator in Zoology: Hugh M. Smith.

Associate in Marine Sediments: T. Wayland Vaughan.

Collaborator in Zoology: Robert Sterling Clark.

Collaborators in Biology: A. K. Fisher, David C. Graham.

DEPARTMENT OF GEOLOGY:

R. S. Bassler, head curator.

Division of Physical and Chemical Geology (systematic and applied): W. F.
Foshag, curator; Edward P. Henderson, assistant curator.*Division of Mineralogy and Petrology*: W. F. Foshag, curator; Frank L. Hess,
custodian of rare metals and rare earths.*Division of Stratigraphic Paleontology*: Charles E. Resser, curator; Gustav A.
Cooper, assistant curator; Jessie G. Beach, aid; Margaret W. Moodey,
aid for Springer collection.Section of Invertebrate Paleontology: T. W. Stanton, custodian of
Mesozoic collection; Paul Bartsch, curator of Cenozoic collection.

Section of Paleobotany: David White, associate curator.

Division of Vertebrate Paleontology: Charles W. Gilmore, curator; Charles L.
Gazin, assistant curator; Norman H. Boss, chief preparator.

Associate in Mineralogy: W. T. Schaller.

Associates in Paleontology: E. O. Ulrich, August F. Foerste.

Associate in Petrology: Whitman Cross.

DEPARTMENT OF ARTS AND INDUSTRIES:

Carl W. Mitman, head curator.

Division of Engineering: Frank A. Taylor, curator.Section of Mechanical Technology: Frank A. Taylor, in charge; Fred C.
Reed, scientific aid.

Section of Aeronautics: Paul E. Garber, assistant curator.

Section of Mineral Technology: Carl W. Mitman, in charge; Chester G.
Gilbert, honorary curator.*Division of Textiles*: Frederick L. Lewton, curator; Mrs. E. W. Rosson, aid.

Section of Wood Technology: William N. Watkins, assistant curator.

Section of Organic Chemistry: Aida M. Doyle, aid.

Division of Medicine: Charles Whitebread, assistant curator.*Division of Graphic Arts*: R. P. Tolman, curator.

Section of Photography: A. J. Olmsted, assistant curator.

Loeb Collection of Chemical Types: Aida M. Doyle, in charge.DIVISION OF HISTORY: T. T. Belote, curator; Charles Carey, assistant curator;
Mrs. C. L. Manning, philatelist.

ADMINISTRATIVE STAFF

Chief of correspondence and documents.—H. S. BRYANT.*Assistant chief of correspondence and documents*.—L. E. COMMERFORD.*Superintendent of buildings and labor*.—J. S. GOLDSMITH.*Assistant superintendent of buildings and labor*.—R. H. TREMBLY.*Editor*.—PAUL H. OEHSER.*Engineer*.—C. R. DENMARK.*Accountant and auditor*.—N. W. DORSEY.

Photographer.—A. J. OLMSTED.
Property clerk.—W. A. KNOWLES.
Assistant Librarian.—LEILA F. CLARK.

NATIONAL GALLERY OF ART

Acting director.—RUEL P. TOLMAN.

FREER GALLERY OF ART

Curator.—JOHN ELLERTON LODGE.
Associate curator.—CARL WHITING BISHOP.
Assistant curator.—GRACE DUNHAM GUEST.
Associate.—KATHARINE NASH RHOADES.
Assistant.—ARCHIBALD G. WENLEY.
Superintendent.—JOHN BUNDY.

BUREAU OF AMERICAN ETHNOLOGY

Chief.—MATTHEW W. STIRLING.
Ethnologists.—JOHN P. HARRINGTON, JOHN N. B. HEWITT, TRUMAN MICHELSON,
 JOHN R. SWANTON, WILLIAM D. STRONG.
Archeologist.—FRANK H. H. ROBERTS, JR.
Associate anthropologist.—WINSLOW M. WALKER.
Editor.—STANLEY SEARLES.
Librarian.—ELLA LEARY.
Illustrator.—EDWIN G. CASSEDY.

INTERNATIONAL EXCHANGES

Secretary (in charge).—CHARLES G. ABBOT.
Chief clerk.—COATES W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK

Director.—WILLIAM M. MANN.
Assistant Director.—ERNEST P. WALKER.

ASTROPHYSICAL OBSERVATORY

Director.—CHARLES G. ABBOT.
Assistant director.—LOYAL B. ALDRICH.
Research assistant.—FREDERICK E. FOWLE, JR.
Associate research assistant.—WILLIAM H. HOOVER.

DIVISION OF RADIATION AND ORGANISMS

Director.—CHARLES G. ABBOT.
Assistant director.—EARL S. JOHNSTON.
Research and consulting physicist.—FREDERICK S. BRACKETT.
Associate research assistant.—EDWARD D. MCALISTER.
Assistant in radiation research.—LELAND B. CLARK.
Research associate.—FLORENCE E. MEIER.

REPORT OF THE SECRETARY OF THE SMITHSONIAN INSTITUTION

C. G. ABBOT

FOR THE YEAR ENDING JUNE 30, 1934

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to submit herewith my report showing the activities and condition of the Smithsonian Institution and the Government bureaus under its administrative charge during the fiscal year ended June 30, 1934. The first 10 pages contain a summary account of the affairs of the Institution, and appendixes 1 to 10 give more detailed reports of the operations of the National Museum, the National Gallery of Art, the Freer Gallery of Art, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the Division of Radiation and Organisms, the Smithsonian Library, and of the publications issued under the direction of the Institution. On page 70 is the financial report of the executive committee of the Board of Regents.

OUTSTANDING EVENTS

Reduced income, both private and governmental, has greatly restricted the scope and amount of the Institution's researches, explorations, and publications. Nevertheless, the year has been exceptionally fruitful. Specimens of the rarest merit have been purchased for the Freer collections. Fifteen papers were published descriptive of new forms of marine life discovered by the first Johnson-Smithsonian Deep-Sea Expedition to the Puerto Rican Deep in 1933. Very significant progress is believed to have been made in the study of the dependence of weather on the variation of the sun's heat. Indeed the indications already furnished by many test forecasts seem almost to verify the hope that Secretary Langley voiced 40 years ago, namely, that the study of the sun will yield means of forecasting weather for seasons and even years in advance. In the Division of Radiation and Organisms very accurate data have been obtained showing the influence of wave lengths of radiation upon the absorption of carbon dioxide by wheat plants and upon the bending of plants toward the light. Interesting results have also been gained on the growing of wheat to maturity in air containing enhanced amounts of carbon dioxide. Several papers were completed on the action of radiation to

promote or inhibit the multiplication of algae. The Institution participated, through Dr. W. D. Strong, in an expedition to Honduras, where much new ethnological and archeological information was gained in a field heretofore little worked. The Government's relief program under the Civil Works Administration supported several very considerable archeological excavations in five States in charge of members of the Institution's staff. Especially interesting was the excavation of a large mound near Macon, Ga. Six different levels of occupation were uncovered there. Dr. Alan Mozley continued his investigations of the molluscan fauna of Siberia under the Walter Rathbone Bacon traveling scholarship. The Institution received a bequest amounting to over \$58,000 from William Herbert Rollins, of Boston, to establish a fund to be known as "The Miriam and William Rollins Fund for Exploration Beyond the Boundary of Knowledge." Outstanding among the year's publications were the Eighth Revised Edition of the Smithsonian Physical Tables, greatly enlarged and brought up to date, and a supplemental volume of the World Weather Records, covering the period 1921 to 1930.

SUMMARY OF THE YEAR'S ACTIVITIES

National Museum.—The appropriations for the year totaled \$654,871, a decrease of \$46,585 from those of the previous year. New specimens added to the collections numbered 340,780. These included valuable anthropological materials from Africa, Honduras and Nicaragua, Australia, Alaska, and various regions in this country. In the field of biology, large sendings of mammals, birds, and other forms were received from China and Siam; unusually large collections of insects were accessioned, one numbering 69,000 specimens; and many important plant specimens were added to the National Herbarium, particularly from North, South, and Central America, the Hawaiian Islands, Poland, and French Indo-China. Among the large number of rocks, minerals, gems, meteorites, and fossils received by the department of geology may be mentioned the collection of 2,500 rocks assembled by the late Dr. Henry S. Washington, one of the world's leading petrologists, and the Tellef Dahll collection of minerals from the pegmatites of southern Norway. In arts and industries, the most important accession was the Wright brothers' airplane in which Calbraith P. Rodgers completed the first flight across the United States, in 1911. To the historical collections, Mrs. Herbert Hoover added a costume worn by her at the White House during her husband's administration. Although field work was greatly restricted by curtailed appropriations, nevertheless a number of expeditions went out through various special arrangements in the interest of the Museum's scientific work. Visitors to the several Museum buildings totaled 1,463,375.

National Gallery of Art.—Three special exhibitions were held during the year, one of works by Negro artists, another of miniatures by Charles Fraser, and the third of water colors of the American Navy, by Lt. Arthur E. Beaumont, U. S. N. R. A number of art works were accessioned during the year subject to transfer to the Gallery if approved by the National Gallery of Art Commission. Under the fund established by the bequest of the late Catherine Walden Myer, three miniatures were purchased for the Gallery. A descriptive catalog was prepared of necklaces, jewels, and other miscellaneous art objects contained in the Gellatly Collection, and a translation was made of the Salmony Catalog of the Chinese glass in the same collection.

Freer Gallery of Art.—The year's additions to the collection include an example of Arabic bookbinding, Chinese bronzes, Chinese and Persian ceramics, Arabic glass, Chinese gold work, an Armenian manuscript, and Chinese, East Christian (Byzantine), Indian, and Persian paintings. Curatorial work was devoted to the study of Armenian, Chinese, Japanese, Arabic, and Persian texts associated with recent acquisitions. During the year 708 objects and 433 photographs of objects were submitted to the Curator for an opinion as to their identity, provenance, and historical or esthetic value. Visitors totaled 117,363, and 68 groups were given docent service. The Gallery's field expedition in China was recalled, as present conditions there render cooperative archeological work practically impossible. The expedition has to its credit, however, a moderate amount of positive scientific achievement, as shown by the results of its surveys and excavations.

Bureau of American Ethnology.—Under the C. W. A. relief program a number of archeological investigations were conducted under the direction of the scientific staff of the Bureau. In Florida, mounds and habitation sites were excavated near Bradenton, on Perico Island, at several points on the east coast, and in the vicinity of Lake Okeechobee. In Georgia, a large mound group was excavated near Macon. In Tennessee, work was done on mounds in Shiloh National Military Park. In California, archeological excavations were undertaken at Buena Vista Lake, Kern County. Besides employing large numbers of men, these projects resulted in the amassing of a considerable amount of new information on the Indian cultures of the regions involved. Members of the staff also carried on other archeological investigations in Georgia and Arizona, field studies of the California Indians, linguistic studies, and further researches on the Iroquois tribes.

International Exchanges.—In the official exchange with other countries of governmental and scientific documents, the exchange service handled during the year a total of 675,980 packages, weighing 624,741

pounds. The clearance of consignments arriving at New York for the Institution was taken over in April 1934 by the United States Government Despatch Agent.

National Zoological Park.—Accessions to the collection during the year numbered 772, and removals through various causes totaled 1,030, leaving the collections at the close of the year at 2,238 animals, representing 707 different species of mammals, birds, reptiles, and other forms. The number of visitors was 2,978,041, including groups from 586 schools in 20 States and the District of Columbia. With the help of the C. W. A. and of the Work Planning and Job Assignment Committee of the District, a large number of important projects involving improvements to buildings and grounds were completed. The great need of the Zoo continues to be the carrying out of its program of providing adequate buildings for the splendid collection of animals.

Astrophysical Observatory.—A statistical analysis of the solar-constant observations made at the Mount Montezuma station led to an improved method of reduction of the observations; this method was applied at Mount Montezuma and resulted in increased accuracy. The study of the relations of solar variation to the weather has shown marked progress. The daily solar-constant values from Table Mountain, Calif., have been broadcast. A new station for solar-constant observations has been established on Mount St. Katherine, near Mount Sinai, Egypt. The Eighth Revised Edition of the Smithsonian Physical Tables, greatly enlarged, prepared by Mr. Fowle, was published during the year.

Division of Radiation and Organisms.—The following investigations were undertaken by the scientific staff of the division: Measurements of the absorption of carbon dioxide from the air by wheat plants under the influence of radiation; measurements of the effect of radiation on worm eggs; the development of powerful apparatus for visible and infrared absorption spectral investigations; growth experiments with special radiation on tomatoes; measurements of phototropism in oat coleoptiles; experiments to determine the influence on wheat of modifying the supply of carbon dioxide; and studies of the influence of radiation of various wave lengths on the multiplication of the alga *Chlorella vulgaris*.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, according to the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without

authority to administer the trust directly, and, therefore, constituted an "establishment" whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The affairs of the Institution are administered by a Board of Regents whose membership consists of "the Vice President, the Chief Justice, three Members of the Senate, and three Members of the House of Representatives, together with six other persons other than Members of Congress, two of whom shall be resident in the city of Washington and the other four shall be inhabitants of some State, but no two of them of the same State." One of the regents is elected chancellor of the board. In the past the selection has fallen upon the Vice President or the Chief Justice, and a suitable person is chosen by the regents as Secretary of the Institution, who is also secretary of the Board of Regents, and the executive officer directly in charge of the Institution's activities.

No changes occurred in the personnel of the Board during the year. Dr. John C. Merriam, whose 6-year term as a citizen (District of Columbia) regent expired on December 20, 1933, was reappointed as a member of the Board by joint resolution of Congress approved April 20, 1934, for the statutory term of 6 years.

The roll of regents at the close of the year was as follows: Charles Evans Hughes, Chief Justice of the United States, Chancellor; John N. Garner, Vice President of the United States; members from the Senate—Joseph T. Robinson, M. M. Logan, David A. Reed; members from the House of Representatives—T. Alan Goldsborough, Edward H. Crump, Charles L. Gifford; citizen members—Irwin B. Laughlin, Pennsylvania; Frederic A. Delano, Washington, D. C.; John C. Merriam, Washington, D. C.; R. Walton Moore, Virginia; Robert W. Bingham, Kentucky; Augustus P. Loring, Massachusetts.

Proceedings.—Only one meeting of the full Board was held during the year—the annual meeting on December 14, 1933. The regents present were Chief Justice Charles Evans Hughes, chancellor, Senator M. M. Logan, Senator David A. Reed, Frederic A. Delano, Hon. Irwin B. Laughlin, Dr. John C. Merriam, Hon. R. Walton Moore, and the Secretary, Dr. Charles G. Abbot.

The Secretary presented his annual report, detailing the activities of the several Government branches and of the parent Institution during the year, and Mr. Delano presented the report of the executive committee, covering financial statistics of the Institution. The Secretary also presented the annual report of the National Gallery of Art Commission.

The Secretary presented his usual special report reviewing the outstanding events of the year, emphasizing the urgent need for the

erection of the proposed wings or extensions on the east and west sides of the Natural History Building of the National Museum, and the efforts which had been made by members of the board as well as by himself to obtain the necessary funds to erect these extensions. Dr. Wetmore, Assistant Secretary, described certain improvements going forward at the National Zoological Park, under grants from the Civil Works Administration, and also spoke of archeological investigations which were being carried on in five States under similar grants.

The Board adopted a resolution expressing its appreciation to Eldridge R. Johnson and his son, E. R. Fenimore Johnson, for their cooperation in the biological work of the Institution in connection with the expedition to the Puerto Rican Deep. The meeting then adjourned, and the regents inspected the special exhibits in the Secretary's office illustrative of some of the Institution's recent activities.

FINANCES

A statement will be found in the report of the executive committee, page 70.

MATTERS OF GENERAL INTEREST

JOHNSON-SMITHSONIAN DEEP-SEA EXPEDITION

In last year's report was described the first Johnson-Smithsonian Deep-Sea Expedition to the Puerto Rican Deep, sponsored by Eldridge R. Johnson, of Philadelphia, and directed by Dr. Paul Bartsch, curator of the division of mollusks in the National Museum. This first expedition is the beginning of an extensive program of oceanographic investigation, for which Mr. Johnson has generously made available his yacht *Caroline*, completely equipped at his expense with the most modern devices for such work. The first cruise resulted in very large and valuable catches of marine forms, and these were separated into their component groups and turned over to specialists for report. During the past year 15 papers describing some of the new forms were published in the Smithsonian Miscellaneous Collections, the groups so far partially covered being mollusks, crabs, crinoids, nematodes, trematodes, annelids, fishes, brachiopods, amphipods, brittlestars, and starfishes. Other papers in this series will appear during the coming year.

RESEARCHES IN EUROPEAN ARCHIVES

Dr. C. U. Clark completed during the year his research work among the European archives under the grant furnished to the Smithsonian Institution by Hon. Charles G. Dawes in 1929. These researches carried Dr. Clark through the principal depositories in Italy, Spain,

Portugal, France, and England, and resulted in the discovery of much new material relating to the early history of exploration in America. Besides many letters and short documents containing much interesting information regarding the customs of the Indians of South and Central America and their relationship to their Spanish conquerors, the following list gives the titles of some of the principal manuscripts which have been brought to light and which would be published if funds were available:

"Compendio y Descripcion de las Indias Ocidentales", by Fray Antonio Vasquez de Espinosa. 1628-29. Something over 300,000 words. A comprehensive report on Central and South America, including New Mexico, some of California, a part of the West Indian Islands, and the Philippines. Original in Vatican Library.

"Apologetica historia summaria, quanto a las calidades, dispusicion, descripcion, cielo y suelo destas tierras; y condiciones, naturales policies, republicas, maneras de biuir, y costumbres de las gentes destas Indias occidentales y meridionales, cuyo imperio soberano pertenece a los Reyes Catholicos." MS. of 216 folios. Mentions Hispaniola, New Spain, Vera Paz, Peru. Some interesting notes on Indian customs. In the Vatican Library.

"Tassaciones de la provincia de Yucatan, hechas en la Real audiencia de los Conffines que Reside en la ciudad de Sanctiago de Goatemala." 1549-1551. Folios 307 to 401. Part of a document of 400 folios dealing with the assessments of Guatemala, Nicaragua, Yucatan, and Comayagua (Honduras). This is a most interesting tax list of Yucatan and Tabasco, listing many settlements now either abandoned or combined with others; showing the number of adult Indian tax payers in most of the towns; indicating the exact amount to be paid yearly in products of the land—corn, fowls, honey, beeswax, fish, cacao, cloth, etc. In Archivo General de Indias.

"Relacion historical eclesiastica de la provincia de Yucatan . . ." Written in 1635 by the Bachiller Francisco de Cardenas i Balencia, clerigo della. 67 folios. Detailed and interesting description of Merida; lists various towns. In British Museum.

"Vicita a su Obispado por el Illustrisimo Senor Fr. Don Ygnacio Padilla." 1757. Folios, 36. A report by Bishop Ignacio Padilla of his inspection of the Bishopric of Yucatan. Notes on the towns, distances between them, population, etc. In British Museum.

Archivo General de Indias. Guatemala 11, Doc. 38 (2). Evidently a report or letter, signed by Dr. Alonso Criado de Castilla, dated May 15, 1600. Folios 4 to 6v. A description of the manners and customs of the Indians of Vera Paz.

Account book of the town of San Juan Amatitlan, Guatemala, 1559-1562. About 72 folios. In Archivo General de Indias. Written partly in Pokonchi, a Maya language, and Pipil, which is a Nahuatl dialect, and apparently by native scribes. A document interesting for its presentation of some of the earliest of this linguistic material.

A letter from the Adelantado Pascual Aadagoya to King Charles of Spain, dated Gali, Sept. 15, 1540; 21 pages. Treats of his voyage from Panama to west coast of South America to take charge; explorations in the present Ecuador, founding of towns, pacification and conversion of natives, uprisings, etc., quarrels with Pizarro. Madrid, Biblioteca Nacional 19267.

"Plano sobre a civilização dos Indios do Brasil, E principalmente Para a Capitania da Bahia . . ." written by Domingos Alvez Munis Barrieto, Lt. Col. of Cavalry at Bahia. In Ajuda (51-IV-41). 122 folios. On the Indians of Brazil, and an indictment of their treatment by the Jesuits.

Codex Berberini Latino 241. Vatican. "Libellus de Indorum medicinalibus herbia." 1552. By one "Joannes Badianus, natione Indus, patria Xuchimilcanus, ejesdem collegii (i. e., Sanotae Crucis, Tlatilulci) praelector." A list of Mexican medicinal plants, each illustrated in aquarelle, with native names and description and exposition on use in Latin. The "Joannes Badianus" was an Indian, of Xuchimilco, trained by the Franciscans. 63 folios, 6 by 8¼. Characterized as being probably the earliest American botanical and medicinal plant ms.

WALTER RATHBONE BACON TRAVELING SCHOLARSHIP

The Walter Rathbone Bacon scholarship, "for the study of the fauna of countries other than the United States", was held during 1932 and 1933 by Dr. Alan Mozley, who conducted a study of the molluscan fauna of Siberia. The scholarship was later extended to cover 1934, and Dr. Mozley continued his investigations during the past year, in the course of which he made a 3-months' journey through the forest steppe to the south of Omsk. During the winter he worked on his collections in Edinburgh.

In the early summer of 1934 Dr. Mozley turned in a manuscript describing the new mollusks discovered in the course of his work, and this paper will appear in the Smithsonian Miscellaneous Collections early in the next fiscal year. A full report on the fauna as a whole will be made later, when Dr. Mozley has completed his studies.

THIRD ARTHUR LECTURE

In 1931 a bequest was received from James Arthur for the promotion of a series of lectures at the Institution dealing with various aspects of the relation of the sun to the planets, the stars, the weather, and human life. The third Arthur Lecture was given by Dr. Charles G. Abbot, Secretary of the Institution, in the auditorium of the National Museum on February 26, 1934, the subject being "How the Sun Warms the Earth." The speaker dealt with the sun as the earth's source of heat, power, plant growth, and weather, and as a type of the radiative features of the stars. The lecture will be published in the General Appendix to the 1933 Smithsonian Report, now in press.

BEQUESTS

Rollins bequest.—In the will of the late William Herbert Rollins, of Boston, the Institution was named a beneficiary, and during the year the sum of \$58,580 was received under this bequest to establish a fund to be known as "The Miriam and William Rollins Fund for Exploration Beyond the Boundary of Knowledge." The conditions of the trust are as follows:

... the interest of the whole Miriam and William Rollins Fund is to be used for five years to confirm my experiments on the drag of the light medium in the magnetic field. After 5 years one half of the interest of the whole fund is to be added each year to the Principal.

Forever the other half to be used for experiments. The object of this plan is to provide a constantly increasing amount of money each year for experiments, for these will each year become more difficult and recondite.

I direct no part of the money shall ever be used except for pushing forward the bounds of physics and chemistry.

I cannot foresee what will be the nature of the experiments, beyond those stated, but their cost will constantly increase as time goes on and will require the time of great and devoted experimenters. I desire that no part of the money shall ever be used for any other purpose than for the most difficult problems in physics and chemistry, as these are what have most interested me, and to aid in their solution.

Plans are now being worked out to promote researches that will carry out the wishes of the donor.

Reid bequest.—The will of Addison T. Reid, who died in 1902, provided for the payment of the income upon the property to certain persons, and upon their death for the payment of the principal of the estate to the Smithsonian Institution to found a chair in biology in memory of the testator's grandfather, Asher Tunis. During the past year, the last of the beneficiaries, Harriet Reid, died, and the Institution was notified that the sum of \$5,010 would be added to other funds already on hand under the Addison T. Reid bequest. At the close of the year the funds had not actually been received at the Institution.

EXPLORATIONS AND FIELD WORK

In spite of its greatly decreased resources, both governmental and private, the Institution sent out or took part in 13 field expeditions in the furtherance of its research program. The new solar observing station on Mount St. Katherine, Sinai Peninsula, Egypt, was occupied and regular observations begun. Drs. Remington Kellogg and C. Lewis Gazin searched the shore of Chesapeake Bay for the fossil bones of extinct marine mammals. Dr. Waldo L. Schmitt served as a member of the scientific staff of the 1933 Hancock expedition to the Galapagos Islands. Capt. R. A. Bartlett continued his scientific studies of the animal and plant life of the Arctic on behalf of the Institution on the 1933 Norcross-Bartlett Arctic Expedition. Dr. Hugh M. Smith took every opportunity, as in former years, to collect Siamese natural history material for the Institution. Dr. Walter Hough investigated the remains of ancient Indian irrigation canals in Arizona. Frank M. Setzler excavated Indian cave deposits in southwestern Texas, and later conducted archeological studies of a group of mounds near Marksville, La. Dr. F. H. H. Roberts, Jr., excavated the remains of a small Indian village near Allantown, Ariz., which had been built, occupied, and abandoned during the ninth century. Dr. W. D. Strong represented the Institution on an archeological expedition to a little-known region of Honduras. John

P. Harrington studied the early history of the California Indians, rescuing valuable information from old Indian informants. Miss Frances Densmore continued her studies of Indian music, this year among the Indians of the Gulf States.

All the expeditions are briefly described and illustrated in the pamphlet entitled "Explorations and Field Work of the Smithsonian Institution in 1933", Smithsonian publication no. 3235.

PUBLICATIONS

The series of publications issued by the governmental scientific bureaus of the Institution—the National Museum and the Bureau of American Ethnology—bore the brunt of the reduction in appropriations suffered by the Institution as a result of the economy drive. The printing funds for the year were so reduced that the bulletins and proceedings of the Museum and the bulletins of the Bureau had to be suspended entirely. These series present to the world the results of fundamental researches in many branches in science, and their suspension is a serious blow to the Institution's program of diffusion of knowledge.

A total of 71 volumes and pamphlets were published during the year, most of these having been paid for from the private funds of the Institution; 57 were issued by the Institution proper, 12 by the the National Museum, and 2 by the Bureau of American Ethnology. The number of publications distributed was 136,091.

LIBRARY

The accessions to the Smithsonian library during the year numbered 6,278 volumes and 8,191 pamphlets and charts, bringing the total number of items in the library to 833,746. Most of the additions were exchanges for Smithsonian publications, but there were also the usual large number of gifts from organizations and individuals. With the assistance of 34 C. W. A. workers assigned to the library, a number of special projects were carried to various stages of completion; these included classifying and indexing a large collection of aeronautical material, cataloging several special collections of scientific pamphlets, and continuing the preparation of a union catalog of the material in the various libraries of the Institution.

Respectfully submitted.

C. G. ABBOT, *Secretary*.

APPENDIX I

REPORT ON THE UNITED STATES NATIONAL MUSEUM

SIR: I have the honor to submit the following report on the condition and operation of the United States National Museum for the fiscal year ended June 30, 1934.

Appropriations for the maintenance of the National Museum for the year totaled \$654,871, which was \$46,585 less than for the previous year. About 40 percent of this decrease was in the printing and binding allotment, which resulted virtually in the abandonment of the publication program for the year.

COLLECTIONS

Expeditions and purchases were greatly curtailed by the reduction of appropriations, but additions of valuable material to the Museum collections continued in all departments, mainly by gift from outside individuals and organizations. New material came in 1,842 separate accessions, with a total of 340,780 specimens divided as follows: Anthropology, 9,599; biology, 289,347; geology, 30,747; arts and industries, 5,832; history, 5,255. Gifts of specimens to schools and other educational institutions numbered 7,197 specimens. Exchanges of duplicate material with other organizations and with individuals totaled 16,356 specimens, and 30,065 specimens were lent to workers outside of Washington.

Following is a summary of the more important accessions received during the year in the various departments:

Anthropology.—The C. C. Roberts ethnological collection from Africa was augmented by splendid examples of wood carving from the Ivory Coast, Nigeria, Gold Coast, and Cameroons; wooden drums and other musical instruments from Nigeria; and many other objects representing the handiwork of the tribes of these countries. Important collections transferred from the Bureau of American Ethnology include Sumu and Misketo ethnologica from the Honduran and Nicaraguan coasts gathered by Dr. W. D. Strong while a member of the Haskell-Smithsonian expedition. A collection of stone implements used in the daily life of Australian and Papuan tribes was given by Joel H. DuBose.

A remarkable gift from Kokichi Mikimoto, prominent in the culture pearl industry of Japan, is a miniature replica of Mount Vernon executed entirely in worked pieces of mother-of-pearl and studded

and embellished with thousands of graduated pearls. This model was displayed during the 1933 season at the Century of Progress Exposition in Chicago.

From Alaska came 3,950 artifacts collected by James A. Ford and M. B. Chambers; from Palestine 1,081 flint objects from Paleolithic cave deposits near Haifa, collected by the American School of Prehistoric Research and the British School of Archeology in Jerusalem; from Louisiana 1,771 specimens of stone and pottery collected by Frank M. Setzler for the Bureau of American Ethnology near Marks-ville; from eastern Arizona 647 artifacts from Basket Maker III and Pueblo I, II, and III sites collected by Dr. F. H. H. Roberts, Jr., for the Bureau of American Ethnology; from Cumberland Island, Ga., part of an aboriginal dugout canoe bequeathed by the estate of Lucy Coleman Carnegie.

Skeletal material received included 65 lots of bones from Indian burials at Port Tobacco, Md., from Judge William J. Graham; 49 skulls from St. Lawrence Island, Alaska, collected and presented by the Alaska Agricultural College and School of Mines; 37 skulls and skeletons from the Sacramento Valley, Calif., given by Robert F. Heizer; and 16 skulls from the same area, donated by Dr. Alš Hrdlička.

Biology.—The biological material accessioned came from a wide variety of localities. From the Province of Szechwan, China, Dr. D. C. Graham sent 229 mammals, 95 bird skins, and 31 skeletons, including a series of the rare bird *Cholornis*, new to the Museum, a large number of insects, 229 mollusks, and many other forms. Dr. Hugh M. Smith's sendings from Siam included 44 mammals, 444 bird skins, 2,387 insects, and 409 mollusks. W. N. Beach donated nearly 2,000 eggs of South African birds, adding 200 forms not previously represented in the Museum. From India came specimens of birds from Dr. W. L. Abbott and the Roerich Museum.

Dr. C. E. Burt made a large collection of reptiles and amphibians in the southeastern States for the Museum. Among important fishes received were 31 from Baffin Land and other northern waters collected by the Norcross-Bartlett expedition under Capt. Robert A. Bartlett.

The most important entomological addition during the year was a collection of about 69,000 insects (including 51,000 named beetles) made by the late H. F. Wickham and presented by Mrs. Wickham. Over 61,000 insects were received from J. C. Bridwell, collected by him during his travels in Africa, Australia, North America, and the Hawaiian Islands. Frank Johnson made a generous donation of 2,000 Lepidoptera.

Additions to the marine invertebrate collection included a valuable lot of earthworms from Dr. Frank Smith, representing his lifetime

gathering of species from many parts of the world; a collection of Crustacea brought together by the late Charles C. Nutting and presented by the State University of Iowa; an excellent series of Crustacea from the 1934 Hancock Galapagos expedition; a large number of specimens from Baffin Land from Captain Bartlett, who also sent 420 mollusks. Other mollusks received included over 1,500, chiefly North American, from Mrs. H. F. Wickham, 1,680 from the Hawaiian Islands from J. C. Bridwell, 500 from west Florida from G. S. Barnes, and about 2,100 from Panama from Dr. James Zetek. From the Zoological Museum at Copenhagen came 221 crinoids, being part of a collection made by Dr. Th. Mortensen in the East Indies and western Pacific. Other important echinoderms came from the Bay of Bengal, Arabian Sea, China Sea, and Sea of Okhotsk.

In the National Herbarium additions totaled nearly 39,000 plant specimens, particularly from Guatemala, Peru, Mexico, Argentina, the Hawaiian Islands, Brazil, Yucatan, China, Labrador, Poland, Colombia, French Indo-China, and various parts of the United States.

Geology.—Through the income of the Roebling fund there were added 955 minerals, 16 gems, and 28 meteorites (13 new to the Museum). Of these, the most important accession was the Tellef Dahll collection, largely of minerals from the pegmatites of southern Norway gathered before 1872. The outstanding specimen of this lot is a 1½-pound prismatic crystal of thorite. The Canfield collection was enhanced by a series of diamond crystals from the Belgian Congo, and valuable specimens of ruby spinel, sapphire, tourmaline, and garnet from Ceylon, Brazil, and Madagascar were added to the Isaac Lea collection through the Chamberlain fund. The American Gem & Pearl Co. donated an unusually large and brilliant garnet and a small brown beryl from North Carolina. President Roosevelt deposited in the Museum 38 specimens of marbles cut into various ornamental forms.

The petrological series received its most important accession in years—the collection of rocks assembled by the late Dr. Henry S. Washington, one of the world's leading petrologists, consisting of about 2,500 specimens, which have formed the basis of many of the donor's published researches.

The paleontological collections were greatly enhanced by the addition of excellent fossil echinoids and starfishes from Iowa; brachiopods from New Zealand, Spain, Russia, India, and United States; 3,200 fossil insects from the H. F. Wickham collection; 10,000 Paleozoic and Cretaceous invertebrate fossils collected and presented by Dr. G. A. Cooper, H. D. Miser, and R. D. Mesler; a large number of Tertiary mollusks from Mexico; and miscellaneous mammal and bird remains from various localities.

Arts and industries.—The most important aeronautic accession was the Wright Brothers' airplane, type E-X, reconstructed with available parts, in which Calbraith P. Rodgers completed the first flight across the United States, in 1911, and presented by the Carnegie Museum of Pittsburgh.

An accession that will undoubtedly prove to be a popular exhibition specimen is the excellent model of the Appian Way prepared and transferred to the Museum by the Bureau of Public Roads, United States Department of Agriculture. It illustrates the methods and materials used in the construction of this famous Roman highway, in 312 B. C.

The models of the sloop yacht *Ariel* and its power dinghy, together with seven marine paintings, constituted a noteworthy gift from John W. Loveland. A Gorin tabulating typewriter of 1886 was presented by the inventor, Frederick P. Gorin.

Seventy-nine specimens of new textiles of American manufacture were added to the collections; 289 specimens of wood from Queensland, Sumatra, and Africa were received in exchange from the New York State College of Forestry, and 374 wood samples from the United States Bureau of Foreign and Domestic Commerce.

History.—Over 5,000 articles of antiquarian or historical interest were added during the year, of which may be mentioned the gift of Mrs. Herbert Hoover for the costumes collection of a green satin dress, a pair of white kid gloves, a pair of satin slippers, a silver lorgnette, and a necklace worn by her at the White House during the Presidential administration of her husband.

The numismatic section received 16 nickel coins from the International Nickel Co., and the American Numismatic Association added 78 specimens to its already large loan collection of recent coins of the world. In addition, 266 specimens of local scrip or emergency paper currency were added. This collection includes examples of such currency issued from 1931 to 1933 by banks, business firms, municipalities, chambers of commerce, and other organizations in 27 States.

EXPLORATIONS AND FIELD WORK

Work in the field was much curtailed through reduction of appropriations. That carried on was mainly financed by grants from the income of invested Smithsonian funds, through such sources as the C. W. A. and P. W. A., by cooperators, or by the investigators themselves.

During the last few weeks of the year, at the request of the United States Bureau of Indian Affairs, Herbert W. Krieger, curator of ethnology, undertook field work, under P. W. A. funds, in the Columbia River Valley in Oregon and Washington, the aim being to salvage

archeological material and information in the area to be flooded by the dam under construction at Bonneville, Oreg.

Frank M. Setzler, assistant curator of archeology, during the latter half of August, directed the excavation and restoration of several Indian mounds, a neighboring village site, and surrounding earthworks near Marksville, Avoyelles Parish, La., in a cooperative project with the city of Marksville. The scientific importance of the observations made lies in the fact that the material remains, local burial customs, and other factors have made it possible to identify the culture of this site definitely as a southeastern variant of the spectacular Hopewell archeological culture previously known in southern Ohio, with related phases appearing in Wisconsin, Iowa, Illinois, Michigan, and Indiana.

Through information from Hon. T. A. Jenkins, Mr. Setzler was sent in mid-April to Proctorville, Ohio, to investigate the occurrence of aboriginal remains in trenches being dug for local water and sewer lines. After observation and study of the skeletons, potsherds, shells, and bone and stone artifacts recovered, Mr. Setzler concluded that part of the town was built on the site of a village once inhabited by Indians considered in Ohio as belonging to proto-historic Fort Ancient Culture, and generally regarded as ancestors of the Ohio Sioux.

Dr. Aleš Hrdlička, curator of physical anthropology, in May went to Kodiak Island, Alaska, to resume archeological excavations at Larsens Bay, where work was carried on 2 years ago.

At the end of May, Dr. C. Lewis Gazin, assistant curator of vertebrate paleontology, assisted by George Sternberg, began work in the Pliocene and Pleistocene formations of southern Idaho, particularly in the *Plesippus* quarry near Hagerman. In August 1933 Dr. Gazin and Dr. Remington Kellogg spent over a week at Governors Run, Md., searching Miocene deposits for remains of fossil cetaceans.

Dr. G. A. Cooper, assistant curator of stratigraphic paleontology, visited Tennessee and Arkansas, where in Paleozoic localities he collected much interesting material. A short trip by Dr. C. E. Resser, curator, resulted in obtaining, among other fossils, a rare starfish from the Ordovician rocks of Pennsylvania.

James Benn, aid in geology, assisted by other members of the geological staff, collected an excellent slab from the Calvert Cliffs of Chesapeake Bay for the exhibition series. He also obtained in the vicinity of Washington a group of Lower Cretaceous lignite logs.

Dr. W. F. Foshag, curator of mineralogy, traveling under the Roebling fund, examined the pegmatite pocket at Topsham, Maine. E. P. Henderson, assistant curator of physical and chemical geology, under the Canfield fund, in company with Frank L. Hess, of the United States Bureau of Mines, in June studied the pegmatites of

the spruce-pine district of North Carolina and obtained good exhibition and study material.

Dr. W. L. Schmitt, curator of marine invertebrates, was again invited by Capt. G. Allan Hancock to accompany an expedition to the Galapagos Islands and the coasts of northwestern South America and Central America on the yacht *Velero III*. The party left Los Angeles on December 30, 1933, and the cruise terminated on March 15, 1934. The new localities visited and the superior dredging equipment provided by Captain Hancock resulted in an unusually valuable collection, adding particularly to knowledge of the carcinological fauna of the regions covered.

Dr. D. C. Graham, of Szechwan, China, resumed explorations in the mountains of western China, making many valuable collections, chiefly of mammals and insects, at altitudes as high as 15,300 feet; and Dr. Hugh M. Smith, of Bangkok, Siam, continued to gather large and valuable collections of animals from various parts of that country, which have added materially to the Museum's representation of the Siamese fauna.

Capt. Robert A. Bartlett, during the course of the Norcross-Bartlett expedition, made extensive gatherings for the Museum of marine vertebrates from Baffin Land northward to Fury and Hecla Straits.

Dr. Alan Mozley, awarded the Walter Rathbone Bacon traveling scholarship under the Smithsonian Institution for the study of land and fresh-water molluscan fauna of Siberia, made a 3-months' expedition through the forest steppe south of Omsk. As during the previous year, he spent the winter in Edinburgh working on his collections.

Dr. G. S. Myers and E. D. Reid, of the division of fishes, continued field work in Virginia collecting fishes with a view to preparing a report on the fishes of that State. Dr. Paul Bartsch, curator of mollusks, as in previous years, made a short trip to the Tortugas to inspect the *Cerion* colonies planted there.

Except for a few days given by E. C. Leonard to collecting plants in the mountains of Virginia, North Carolina, Tennessee, and West Virginia, the only botanical field work during the year was that of Jason R. Swallen, assistant botanist in the section of grasses, under the Department of Agriculture, who visited Brazil to search for grasses. This work was still in progress at the close of the year and was already yielding excellent results, both in extending the ranges of many species and in the discovery of new ones.

During the summer of 1933, Prof. C. E. Burt, of Southwestern College, Winfield, Kans., was engaged in field work for the Museum with a view to collecting a series of turtles in the southern Appalachian system to settle certain taxonomic and zoogeographical problems.

The results were eminently successful, and many turtles, other reptiles, and amphibians were obtained for the collection.

MISCELLANEOUS

Visitors.—Visitors to the various Museum buildings totaled 1,463,375 during the year, an increase of 36,017 over the previous year. Attendance in the several buildings was recorded as follows: Smithsonian Building, 232,183; Arts and Industries Building, 622,090; Natural History Building, 507,948; Aircraft Building, 101,154.

Publications.—As no funds were available for publications other than the annual report, the published output of the Museum was confined to material sent to the printer before July 1, 1933, but appearing after that date. This consisted of 2 Bulletins, 8 Proceedings separates, and 1 separate from the Contributions from the United States National Herbarium. Volumes and separates distributed during the year to libraries and individuals throughout the world aggregated 35,127 copies.

Under the supervision of the editor of the Museum, work was begun and well advanced on the preparation of a comprehensive index to all the publications thus far issued by the Museum, from 1875 to date.

Special exhibitions.—The year was notable for the number of special exhibitions held, the foyer of the Natural History Building being almost continuously occupied by a series of 15 exhibitions sponsored by various educational agencies, such as the American Forestry Association, Save the Redwoods League, the American Association of Museums, the Public Schools of the District of Columbia, the Model Aircraft League, as well as several Government departments. In addition to these, 8 special exhibits of artists' work and 10 of photographic work were conducted by the division of graphic arts.

Organization and personnel changes.—The establishment of a central disbursing office in the Treasury Department and the consequent abolishment of the disbursing office of the Smithsonian at the end of January necessitated a reorganization of the accounting and disbursing work of the Museum. Nicholas W. Dorsey, disbursing agent, on February 1 was given the title of accountant and auditor, and Thomas F. Clark, his deputy, was made assistant accountant and auditor.

The purchasing of heat hereafter from the Government's central heating plant, instead of producing it at the Museum's own plant, resulted in the abolishment of six permanent and several seasonal positions in the power plant.

On July 1, 1933, Leonard C. Gunnell, formerly in charge of the Regional Bureau of the International Catalogue of Scientific Litera-

ture (which was discontinued), was appointed assistant librarian in the Museum for special bibliographic research.

William Blanchard Marshall, assistant curator of mollusks, was retired, at his own request, on April 30, 1934, after 32 years' service, Harald A. Rehder being promoted to succeed him. Mr. Marshall's long association with the Museum was continued on May 1 by his appointment as honorary associate in zoology. Likewise, Dr. Theodore Sherman Palmer, retired biologist of the Bureau of Biological Survey, was appointed honorary associate in zoology on August 1, 1933.

Other employees who left the service through operation of the Civil Service Retirement Act were: Mrs. Nida M. Browne, preparator (15 years' service); John F. Brazerol, Isador S. Dyer, and Joseph G. Adzema, senior mechanics (27, 22, and 9 years, respectively); Samuel McDowell, blacksmith (17 years); August F. Broacker, Alexander M. Cole, James W. Cornell, and Charles A. Sparks, guards (23, 15, 15, and 4 years, respectively—Mr. Sparks with a total of 35 years, the last 4 with the Museum); Mrs. Ella Coleman, Mrs. Roxie A. Burrell, Mrs. Fannie J. Smith, and Mrs. Margaret Hall, charwomen (24, 23, 21, and 5 years, respectively); Scott Ambler and John F. Pinkney, laborers (24 and 16 years, respectively).

Necrology.—The Museum lost through death 2 honorary and 6 active workers during the year, as follows: Edward Johnson Brown, honorary collaborator, division of birds, on February 14, for many years affiliated with the scientific work of the department of biology; Edward William Nelson, honorary associate in zoology, on May 19, for many years associated with the Government's scientific explorations and research; John Merton Aldrich, associate curator of insects, on May 27 (21 years in Government service, the last 15 with the Museum); Ruth Sherwood, stenographer and typist in the department of arts and industries, on September 13 (15 years in Government service, 13 with the Museum); George L. Weber, guard, on February 22 (16 years' service); Mrs. Mary M. Lorance, charwoman, on January 28 (5 years); Mrs. Cassie Whiting, charwoman, on February 15 (10 years); and James P. Bourke, Sr., elevator conductor, on October 21 (15 years).

Respectfully submitted.

ALEXANDER WETMORE,
Assistant Secretary.

Dr. CHARLES G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 2

REPORT ON THE NATIONAL GALLERY OF ART

SIR: I have the honor to submit the following report on the activities of the National Gallery of Art for the fiscal year ending June 30, 1934.

Owing to the fact that the Gellatly collection occupies such a large part of the Gallery, it was necessary to restrict the special exhibitions. One of miniatures was held in the Gallery proper, and two, which required wall space, were shown in the foyer through the courtesy of the National Museum.

APPROPRIATIONS

For the administration of the National Gallery of Art by the Smithsonian Institution, including compensation of necessary employees, purchase of books of reference and periodicals, traveling expenses, uniforms for guards, and necessary incidental expenses, \$29,500.

THE NATIONAL GALLERY OF ART COMMISSION

The thirteenth annual meeting of the National Gallery of Art Commission was held at the Smithsonian Institution on December 12, 1933. The members present were Dr. Charles G. Abbot, Secretary of the Smithsonian Institution, who is an ex-officio member and also the secretary of the Commission; Herbert Adams; Charles L. Borie, Jr.; Joseph H. Gest, chairman; Frederick P. Keppel, John E. Lodge, Frank Jewett Mather, Jr., and Edward W. Redfield. Ruel P. Tolman, curator of the division of graphic arts, and acting director of the National Gallery of Art, was also present.

Secretary Abbot was requested to communicate an expression of the Commission's sympathy to the families of Dr. William H. Holmes and Charles A. Platt, who died April 20 and September 13, 1933, respectively.

The Commission recommended the name of Mahonri Young to the Board of Regents to fill the vacancy caused by the death of Dr. William H. Holmes.

It also recommended to the Board of Regents the reelection for the succeeding term of 4 years of the following members: George B. McClellan, Frederick P. Keppel, and Charles L. Borie, Jr. The

following officers were reelected for the ensuing year: Joseph H. Gest, chairman; Frank Jewett Mather, Jr., vice chairman; and Dr. Charles G. Abbot, secretary. The following were reelected members of the executive committee for the ensuing year: Charles Moore, Herbert Adams, and George B. McClellan. Joseph H. Gest, as chairman of the Commission, and Dr. Charles G. Abbot, as secretary of the Commission, are ex-officio members.

ART WORKS RECEIVED DURING THE YEAR

Accessions of art works by the Smithsonian Institution are as follows:

Portrait of Julia Ward Howe (known as "The Battle Hymn Portrait"), by John Elliott (1858-1925). Presented by Mrs. Maud Howe Elliott "for the collection of prominent Americans."

Portrait of Mrs. Albert J. Myer, by George P. A. Healy, acquired through bill of sale from Miss Gertrude Walden Myer, to be delivered at her death (which occurred June 4, 1934).

Plaster cast of heroic statue of Henry Clay, by Edmond T. Quinn. Gift of the National Commission of Fine Arts, Washington, D. C. This statue formed part of the George Washington Bicentennial Exhibition at the National Museum in 1932.

Plaster model of figure from group entitled "Patriotism", by Adolph Alexander Weinman. Gift of the sculptor, through the National Commission of Fine Arts, Washington, D. C.

THE CATHERINE WALDEN MYER FUND

A bequest of the late Catherine Walden Myer of Washington, D. C., who died February 8, 1922, established under the Smithsonian Institution, a fund for the purchase of first-class works of art for the use and benefit of the National Gallery of Art. The following miniatures have been acquired through this fund:

Two Early American miniatures: Mrs. Alexander Rose, by John Ramage, 1802; Mrs. Rose's brother-in-law, by Archibald Robertson (1765-1835); purchased from Dr. Arthur R. Guerard, Cranford, N. J.

Early American miniature of an "Unknown Man", by Edward Greene Malbone (1777-1807), painted about 1798; purchased from Mrs. Emily Nevill Jackson, London, England.

LOANS ACCEPTED BY THE GALLERY

Self portrait, by George Catlin (1796-1872), painted when the artist was a young man; lent by Miss Mary Cogswell Kinney, New York City.

Two miniatures of John Parke Custis and Martha "Patty" Custis, children of Martha Washington, painted at Mount Vernon in 1772 by Charles Willson Peale (1741-1827); lent anonymously.

An Early American miniature of Thomas Waties, by Charles Fraser (1782-1860); lent by Miss Marie R. Waties, Washington, D. C.

Four miniatures: Virginia Casterton, 1918; Jane Casterton, 1923; Miss Goss, 1910; and Mme. Tamaki Miura, 1918; lent by the artist, Mrs. Eda Nemoede Casterton, Chicago, Ill.

A reproduction in silver, made in England about 1850, of a silver-gilt wine pitcher attributed to Benvenuto Cellini; lent by Capt. Frank O. Ferris, Ballston, Va.

Seven pieces of silver as follows: Hot-water kettle and stand, old English (Britannia Standard), made in London by Paul Lamerie in 1728; teapot, old Irish, made in Dublin by Mathew Walker in 1717; four vegetable dishes and covers, made in London by Wakelin and Taylor in 1791; and punch strainer made in Boston, Mass., by Samuel Minott (1732-1803); lent by Mrs. George Morris, Washington, D. C.

GALLERY LOANS RETURNED

The painting entitled "Indian Burial", by George de Forest Brush, withdrawn by Mr. Brush for special exhibition of his works at the Academy of Arts and Letters, New York City, was returned as a loan to the Gallery May 4, 1934.

Five paintings, the property of the National Gallery, which were on display in the office of the editor of Art and Archaeology, of which magazine the late director of the National Gallery, Dr. W. H. Holmes, was art editor, were recalled on July 21, 1933. The paintings are: Sheep, by Paul Dessar; Marine, by Edward Moran; The Villa Malta, by Sanford Robinson Gifford; Waterfall, by Addison T. Millar; Twilight After Rain, by Norwood Hodge MacGilvary.

The painting by Francesco Guardi (1712-1783) entitled "Ruins and Figures", part of the Ralph Cross Johnson collection, lent to the Art Institute of Chicago for its art exhibit in connection with the Century of Progress Exhibition in Chicago, 1933, was returned November 16, 1933.

The National Gallery's part of the Institution's exhibition at the Century of Progress, Chicago, 1933, consisting of two water colors, "The Maryland Fields", by William H. Holmes (1846-1933), and "The Canyon of the Belle Fourche, Wyoming, 1892", by Thomas Moran (1837-1926); one oil, "A Quiet Nook", by William Hart (1823-1894); and two plaques of Solon-ware from the Alfred Duane Pell Collection, were returned December 4, 1933.

LOANS BY THE GALLERY

Four pastels by Walter Beck, "The Mosby Triptych" and "Christ Before Pilate", were loaned to the Dayton Art Institute, Dayton,

Ohio, for an exhibition of the works of Mr. Beck during the months of November and December 1933. Returned to the Gallery January 4, 1934.

The statue "The Greek Slave", by Hiram Powers, was loaned February 14, 1934, to the Cincinnati Art Museum, Cincinnati, Ohio, for a special exhibition of the works of Hiram Powers. Returned April 12, 1934.

The portrait of Mrs. Price, by William Hogarth, was loaned to the Art Institute of Chicago, Chicago, Ill., for "A Century of Progress Loan Exhibition of Fine Arts", June 1 to October 31, 1934.

WITHDRAWALS BY OWNERS

The portrait of George A. Otis, by Gilbert Stuart (1755-1828), was shipped August 11, 1933, to Roger Ernst, Brookline, Mass., at request of the owner, Mrs. O. H. Ernst.

Two bronzes, "A Teacher" and "An American Student", by Moses Wainer Dykaar (1884-1933), the property of Samuel Rappaport, Los Angeles, Calif., were returned to Mr. Rappaport through Leon Brill, Jr., Washington, D. C., on January 22, 1934.

An oil painting entitled "Mother and Child with St. John", by Andrea del Sarto, was withdrawn July 7, 1933, by Mrs. E. E. Powell, formerly Mrs. W. W. Powell, Washington, D. C., and Oxford, Ohio.

The portrait of the Honorable Richard Rush, copy by an unknown artist from a portrait by T. W. Wood in the possession of the Smithsonian Institution, lent by Mrs. John Biddle Porter (Elizabeth Rush), was withdrawn February 28, 1934, by Mrs. Frederick C. Fearing (Elizabeth Porter Fearing), Bronxville, N. Y., who inherited it from her mother.

SPECIAL EXHIBITIONS

An exhibition of works by Negro artists, sponsored by the Association for the Study of Negro Life and History, Inc., including paintings, drawings, water colors, block prints, wood carvings, etc., was shown in the foyer of the Natural History Building from October 31 to November 6, 1933.

An exhibition of 111 miniatures, the work of Charles Fraser (1782-1860), American miniaturist, was held in the Gallery from March 7 to 27, 1934. Of these, 109 were received direct from an exhibition at Charleston, S. C., the home of the artist, and 2 from Mrs. Benjamin Huger Read, of Baltimore.

An exhibition of 32 water colors of the American Navy, by Lt. Arthur E. Beaumont, U. S. N. R., was held in the foyer of the National Museum from May 16 to 29, 1934.

THE NATIONAL GALLERY REFERENCE LIBRARY

The work of reorganization in the library has been continued with the services of one full-time assistant; from the first week in December until the middle of February additional assistance was given by a part-time C. W. A. worker. Cataloging and classifying has been continued, and considerable time has been given to book selection and ordering, to transferring publications, to checking missing parts in serial publications, to reference work, and to the making of bibliographies on subjects pertaining to art.

The collection has been increased by over 700 publications.

OTHER ACTIVITIES

The Harriet Lane Johnston collection, which has been shown with other miscellaneous works of art, now occupies a smaller gallery by itself.

A selection of early and contemporary American miniatures were on exhibition.

Two cases of Japanese, Chinese, and Korean porcelains from the Alfred Duane Pell and H. Foster Bain collections were arranged for display in the Ralph Cross Johnson Room.

The acting director was detailed to Chicago from July 21 to August 19, 1933, to study the art collections at the Century of Progress Exposition, 1933, and to visit and examine the various art museums and galleries en route. Galleries were visited at Pittsburgh, Pa.; Columbus, Dayton, and Cincinnati, Ohio; Indianapolis, and Notre Dame University, South Bend, Ind.; Chicago, Ill.; Muskegon, Grand Rapids, Lansing, Ann Arbor, and Detroit, Mich.; Toledo, Cleveland, and Youngstown, Ohio; Buffalo, Rochester, and Elmira, N. Y.; and Harrisburg, Pa.

In preparation for an exhibition in the National Gallery of miniatures by Charles Fraser, which was being shown at the Gibbes Memorial Art Gallery, Charleston, S. C., the acting director was detailed from February 12 to March 3, 1934, to visit Charleston for the purpose of examining and studying the collection there, and arranging for the shipment to Washington of such of the miniatures as were available through courtesy of their owners. Visits were made to points farther south, examining galleries and museums at Savannah, Ga.; Sarasota, Orlando, and St. Augustine, Fla.

PUBLICATIONS

TOLMAN, R. P. Report on the National Gallery of Art for the year ending June 30, 1933. Appendix 1, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1933, pp. 13-21.

LODGE, J. E. Report on the Freer Gallery of Art for the year ending June 30, 1933. Appendix 2, Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1933, pp. 22-26.

SEYMOUR, RALPH, and RIGGS, ARTHUR STANLEY. The Gellatly Collection, by Ralph Seymour and Arthur Stanley Riggs. Art and Archaeology, vol. 35, no. 3, pp. 109-125 and 144, 28 illustrations, May-June, 1934. Also reprint.

Catalogue: Exhibition of Works by Negro Artists at National Gallery of Art, Smithsonian Institution. Sponsored by the Association for the Study of Negro Life and History, Washington, D. C., October 31 to November 6, 1933; 4 pp., privately printed for the association.

Catalogue of an Exhibition of Paintings by Arthur Beaumont, Lieutenant, U. S. N. R., "Our Glorious Navy." Privately printed, 4 pp., 1 illustration.

Respectfully submitted,

R. P. TOLMAN, *Acting Director.*

Dr. C. G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 3

REPORT ON THE FREER GALLERY OF ART

SIR: I have the honor to submit the fourteenth annual report on the Freer Gallery of Art for the year ending June 30, 1934:

THE COLLECTIONS

Additions to the collections by purchase are as follows:

BOOKBINDING

- 34.17. Persian, sixteenth century. *Qur'an* binding: dark brown leather (outside) and light brown leather (inside). Decoration in gold tooling, gold cut-work, and gold painting. One panel, 0.375 by 0.246. (Illustrated.)

BRONZE

- 34.3-34.14. Chinese, early Chou dynasty (1122-255 B. C.). A group of 12 blades for shafted weapons, excavated at An-yang, Honan Province. Of various forms and sizes, decorated and plain. One inlaid with mother-of-pearl.
- 34.21. Chinese, T'ang dynasty, seventh to tenth century. A gilt bronze box (0.245 by 0.095 by 0.051), with the cover wrought in an open-work floral design.

CERAMICS

- 34.2. Chinese, Ch'ing dynasty, early eighteenth century. Reign of Yung a-b. Chêng, *Ku Yüeh Hsüan* type. Porcelain bowl (0.053 by 0.102), thin, translucent, white. Decoration: plum-blossoms in reserve in a ground of raspberry red enamel. Mark under foot. Ivory stand.
- 34.18. Persian, thirteenth century, Rhages (Raiy) type. Pottery inkstand (0.077 by 0.109), with four pen sockets. White matte glaze; decorated with seated figures and bands of inscription in over-glaze enamels.

GLASS

- 33.13. Syrian (Arabic), fourteenth century. Large bowl (0.210 by 0.350) of clear blown glass, of grayish amber tint. Decoration includes a frieze of animals on the shoulder, a fabulous bird (*simurgh*) on the bottom inside, and an inscription inside—in polychrome enamels and gold; series of borders in gold line work. (Illustrated.)
- 34.19. Syrian (Arabic), fourteenth century. Vase (0.362 by 0.234) with two large and two small handles, of clear blown glass of grayish amber tint. Decoration in polychrome enamels and gold. (Illustrated.)

- 34.20. Syrian (Arabic), fourteenth century. Bottle (0.497 by 0.248) of clear blown glass of grayish amber tint. Decoration including an inscription on the shoulder in polychrome enamels and gold. (Illustrated.)

GOLD

- 33.10-33.11. Chinese, T'ang dynasty, seventh to tenth century. A pair of iron "sleeve-weights" in the form of plaques (0.069 by 0.064), overlaid with sheet gold repoussé in medium and high relief and inlaid with jade.

MANUSCRIPT

- 33.5. Armenian, ninth to tenth century. The Gospel according to St. Mark and St. Luke (both incomplete). Brown-black vertical uncials on 113 parchment leaves (0.311 by 0.235) plus 1 paper leaf. Illuminated title page (St. Luke), paragraphs (112) and ornamented initials (112).

PAINTING

- 33.8. Chinese, Sung dynasty, thirteenth century. By Chao Mêng-chien. Narcissus: ink on a paper scroll (0.315 by 0.766). Signed.
- 33.9. Chinese, late Sung dynasty, thirteenth to fourteenth century. By Chêng Ssü-hsiao. Orchid: ink on a paper scroll (0.254 by 0.945). Signed.
- 34.1. Chinese, Ming dynasty, fifteenth to sixteenth century. By Shên Chou. River landscape: ink and tints on a paper scroll (0.265 by 1.311). Signed.
- 33.12. East Christian (Byzantine), early twelfth century. Frontispiece to St. Luke's Gospel: St. Luke writing, seated before a lectern. In delicate color on a gold ground (worn) on paper (0.175 by 0.139).
- 34.15. Indian, seventeenth century, Mughal-Rājput. A woman at prayer: an album picture in delicate colors and gold on paper (0.135 by 0.065).
- 34.16. Indian, early seventeenth century, Rājput, Rājasthānī. A wife awaiting her husband's return: an illustration from the *Amaruśataka*; in colors and slight gold on paper (0.140 by 0.165).
- 33.6. Persian, sixteenth century, style of Shāh Qulī. Kneeling figure of an angel as a cup-bearer: in ink, slight tint and gold on paper; illuminated double border (0.193 by 0.108). (Illustrated.)
- 33.7. Persian, sixteenth century, Šafavid. Standing figure of a youth in a blue coat: in opaque colors and gold on paper, with contemporary border (0.159 by 0.069). (Illustrated.)

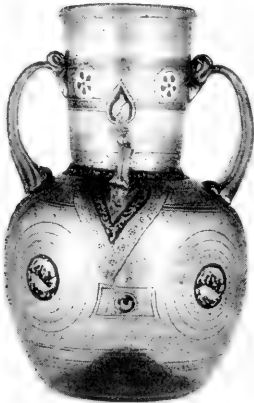
Curatorial work within the collection has been devoted to the study of Armenian, Chinese, Japanese, Arabic, and Persian texts associated with recent acquisitions, and to the studies ordinarily associated with the cataloging and exhibition of objects of Oriental fine arts, including the recent acquisitions. During the past year 708 objects and 433 photographs of objects were submitted to the curator by other institutions or by private persons for an opinion as to their identity, provenance, and historical or esthetic value. Five inscriptions were submitted for translation. Reports on these things were sent to owners or senders. Two early Arabic alphabets in Kufic script of the ninth and twelfth centuries have been compiled and reproduced. Gallery Book IV, with descriptive notes of the



33.15



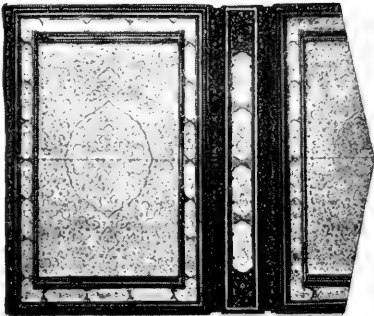
34.20



34.19



33.6



34.17



33.7

Indian collection on view, is almost completed. Cataloging of the Chinese books in the library is being revised.

Changes in exhibition have involved a total of 165 objects, distributed as follows:

- American paintings and prints, 118.
- Arabic mss. 13.
- Arabic painting, 1.
- Chinese bronzes, 18.
- Chinese porcelain, 1.
- East Christian painting, 1.
- Japanese screens, 4.
- Persian paintings, 7.
- Persian pottery, 1.
- Syrian glass, 1.

AUDITORIUM

Several local organizations have met in the auditorium and have been given an illustrated talk by a staff member, preliminary to a view of exhibitions in the galleries above.

November 14.—Twentieth Century Club, Art Section: *Arts and Cultures of the Near East*. Attendance, 51.

February 10.—Women's Club of Chevy Chase, Art Section: *Chinese Arts*. Attendance, 39.

May 19.—District of Columbia Library Association: *Christian and Islamic Mss*. Attendance, 98.

May 14.—The American Federation of Arts, in annual convention, held one session at the Freer Gallery to commemorate the one hundredth anniversary of the birth of James McNeill Whistler. For them a special Whistler exhibition was arranged in Galleries VIII–XII. Attendance, 157.

ATTENDANCE

The Gallery has been open every day from 9 until 4:30 o'clock, with the exception of Mondays, Christmas Day, and New Year's Day.

The total attendance of visitors coming in at the main entrance was 117,340. The total attendance for week days exclusive of Mondays, was 77,810; for Sundays 39,530. The ratio of about 3 to 1, which for several years has existed between Sunday and week-day attendance was maintained, the average Sunday attendance being 760, the average week-day attendance, 250. As heretofore, the highest monthly attendance was reached in April (22,232) and August (11,265). The lowest monthly attendance this year was in February (5,423).

The total attendance on Mondays was 23, making a grand total of 117,363.

There were 2,754 visitors to the offices during the year. Of these, 84 came for general information, 444 to see objects in storage, 64 to examine the building and installations, 229 to study in the library,

55 to see the Washington Manuscripts, 13 to make tracings and sketches from library books, 32 to get permission to make photographs and sketches, 342 to examine or purchase photographs, 115 to submit objects for examination, and 608 to see members of the staff.

Sixty-eight groups, ranging from 1 to 98 persons (total, 565), were given docent service upon request (of these, 2 groups of 3 persons were given docent service on Monday), and 17 groups, ranging from 1 to 17 persons (total, 180) were given instruction in the study rooms.

FIELD WORK

Last autumn we began the disbanding of our field expedition in China and recalled Mr. Bishop to this country, where he arrived in April.

It cannot be said that our attempt to prosecute scientific archeology in China has been the success for which we hoped. On the other hand, it has not been by any means a failure, as the results of our surveys and excavations clearly show. We have to our credit a moderate amount of positive scientific achievement, while on the negative side we have demonstrated to my entire satisfaction that under the present disturbed conditions it is not practicable to continue archeological investigations in China.

PERSONNEL

Mrs. Myron W. Whitney worked at the Gallery between October 11, 1933, and June 25, 1934, on translations of Arabic and Persian inscriptions.

Y. Kinoshita, mounter, returned to the Gallery on October 31, 1933, after a 4 months' visit to Japan.

Mr. and Mrs. Carl Bishop left China for this country on March 17, 1934.

John Pinkney, laborer, retired on May 1, 1934, after nearly 14 years of continuous and faithful service.

Respectfully submitted.

J. E. LODGE, *Curator.*

Dr. C. G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 4

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1934, conducted in accordance with the act of Congress approved June 16, 1933. The act referred to contains the following item:

American ethnology: For continuing ethnological researches among the American Indians and the natives of Hawaii, the excavation and preservation of archeologic remains under the direction of the Smithsonian Institution, including necessary employees, the preparation of manuscripts, drawings, and illustrations, the purchase of books and periodicals, and traveling expenses, \$50,000.00.

SYSTEMATIC RESEARCHES

M. W. Stirling, Chief, devoted the early part of the year to office routine and to the preparation of manuscript relating to past researches. When the Civil Works Administration began to expand its relief program, opportunity was taken to give work to a number of especially equipped unemployed in the translation of manuscript and rare printed material in foreign languages and to the typing and copying of a considerable quantity of rare manuscript material in the archives of the Bureau which has been in danger of disintegrating because of age.

On December 11, 1933, Mr. Stirling left Washington for Florida to supervise archeological projects which he had proposed in connection with the Federal Civil Works Administration relief program. After conference with Civil Works Administration officials at Tallahassee and Jacksonville, work was conducted in the excavation of mounds and habitation sites in the vicinity of the south fork of the Little Manatee River near Bradenton, Fla., and on Perico Island near the mouth of the Manatee River. A sand burial mound was excavated at Englewood in the southern part of Sarasota County. On the eastern coast of Florida, work was conducted on Canaveral Island, at Miami Beach, and at Ormond Beach. In the central part of the State a large site near Belle Glade in the vicinity of Lake Okeechobee was excavated. Because of the amount of labor which it was possible to utilize, much information was obtained which will help to clear up the problems of Southeastern archeology.

During the same period, Mr. Stirling took the opportunity of overseeing the work conducted under the auspices of the Bureau of Ethnology at Macon, Ga., where a large and important mound group was being excavated with the cooperation of the Macon Historical Society. On May 5, Mr. Stirling returned to Washington where he worked on the preparation of the collections obtained during this field work and on the preparation of reports on the different excavations.

Upon the death of the late Gen. Hugh L. Scott, his valuable material on the sign language of the American Indians was added to the Bureau archives. Richard Sanderville, Blackfoot Indian, who had been one of General Scott's principal informants, was brought to Washington in order to go over this material and to supplement it in places which appeared lacking. Opportunity was also taken to make additional motion pictures and a general photographic record of the sign language with Mr. Sanderville as model.

During the earlier part of the year Dr. John R. Swanton, ethnologist, completed the bulletin on the languages of certain Texas tribes, of which mention was made in his last report. This includes all of the linguistic material known to be in existence, both published and unpublished, from the Coahuiltecan, Karankawan, and Tamaulipecan stocks, i. e., all of the Indian tongues of Texas west and south of the Atakapa and Tonkawa, and extending as far into Mexico as the boundaries of the Huastec and Uto-Aztecan tribes.

The remainder of his office work, aside from correspondence, has been devoted mainly to the handbook of Southeastern Indians, mentioned in previous reports. The present draft of this work contains about 1,200 typewritten pages.

At the end of February Dr. Swanton went to Macon, Ga., at the invitation of the Society for Georgia Archaeology, to attend its first meeting and take part in its activities as indicated elsewhere. He remained at Macon for about 3 weeks, visiting archeological sites both in the immediate neighborhood and in other parts of Georgia and making some attempts to locate the route pursued by De Soto in crossing the State in 1540. Dr. Swanton thinks there is little doubt that the crossing point on the Oconee has been identified with the old trail crossing at Carr Shoals, a few miles above Dublin.

Dr. Truman Michelson, ethnologist, devoted the bulk of his time to preparing a paper entitled "The Linguistic Position of Nāwaθinānāna." This consisted of going over Kroeber's published material and establishing the phonetic shifts of the language. It also meant codifying in final form a number of Cheyenne shifts which he had partially worked out in previous years. It also involved clarifying some shifts in Arapaho and Atsina. The special novelty consists in showing how at least certain Algonquian languages became divergent simply by the operation of complex and far-reaching

phonetic shifts. The manuscript was completed before the end of the fiscal year. Toward the close of the fiscal year Dr. Michelson was engaged in working out the phonetic shifts in Natick, an extinct Algonquian language, on the basis of Trumbull's Dictionary.

During the first 6 months of the fiscal year, Dr. John P. Harrington, ethnologist, continued his field studies among the Mission Indians of California, obtaining a rather exhaustive set of notes to accompany the publication of the Boscana manuscript recently discovered by him. It is the long-lost original of the only complete report ever written by a Franciscan missionary on the ethnology of the California Indians. It was written by the Rev. Jeronimo Boscana at San Juan Capistrano Mission on the coast of southern California in 1822, and is a delightfully variant version of the Boscana account entitled "Chinigchinich", published in English translation by Alfred Robinson as an appendix to his *Life in California* in 1846. The task of taking this Spanish original to the oldest surviving Indians and eliciting their comment on its many detailed statements proved fascinating and often went far beyond the scope of the original.

The following 5 months were spent in Washington, D. C., in elaboration of field material. A very literal and careful translation of the newly found manuscript was made, and this translation was published in the *Smithsonian Miscellaneous Collections*, vol. 92, no. 4. Copy of the Spanish text has been prepared, and this with the notes, which exceed several times the bulk of the manuscript, will constitute a later publication by the Smithsonian.

Leaving Washington for California early in June, Dr. Harrington spent 17 days with an old Indian informant who contributed much to the Boscana notes and gave considerable other important information. The end of the fiscal year found him still in the field.

Dr. F. H. H. Roberts, Jr., archeologist, was on leave of absence from the Bureau during the months of July and August 1933. During this time he excavated the remains of a small village of the Pueblo I type. The investigations were carried on $3\frac{1}{2}$ miles south of Allantown, Ariz., on a portion of the site where researches were conducted in the field seasons of 1931, 1932. The 1933 work was done under the auspices of the Laboratory of Anthropology, Santa Fe, N. Mex., as a part of its program of field training for graduate students. The Laboratory and the Bureau cooperated in the investigations of 1931 and the Bureau sponsored those of 1932. Despite its small size, the village excavated in 1933 contributed valuable data on developments occurring within a single phase in the history of the pre-Spanish Pueblo Indians, and this knowledge is being incorporated in the large report on the results of the previous years' investigations at the site.

In the 2 months allotted to the work, two unit dwellings—one consisting of 5 rooms and a subterranean ceremonial chamber,

the other containing 7 rooms and a ceremonial chamber—a third underground structure, and several courts were excavated. The refuse mounds were trenched and 24 burials with accompanying mortuary offerings were uncovered. A few timbers used as roof beams in the structures were sufficiently preserved to make possible their dating by means of dendrochronology. These show that the village was built and occupied between 800 and 850 A. D. Specimens collected include pottery; stone tools, bone implements and ornaments; and some tiny beads made from shells, both red and white in color, which make a string 37 feet $3\frac{1}{2}$ inches in length, one of the longest ever found in the Southwest.

The autumn months were spent in office researches and routine. Drawings were made to illustrate the report on the Arizona work. Information was furnished in response to inquiries. Manuscripts were written detailing various problems in southwestern archeology and explaining the results of the Bureau's activities in that field.

Dr. Roberts left Washington December 16, 1933, for Pittsburg Landing, Tenn., where he began work December 21, on a group of mounds located on the old battlefield in Shiloh National Military Park. The project was one of many sponsored by the C. W. A. and provided for an extensive investigation. The work continued until March 30, 1934. The site is located on a high bluff above the west bank of the Tennessee River and lies between two deep ravines through which flow tributary branches of the main stream. It consists of 7 large mounds, 6 domiciliary and 1 burial, and numerous low elevations which mark the places where dwellings once stood. To the west of the area of occupation is an embankment, extending across the neck of the bluff from one ravine to the other, indicating the former existence of a palisade which protected the community on that side.

Dr. Roberts returned to Washington April 2, and from that time until June 30 worked over material from the Southwest and from Shiloh.

On July 1, 1933, Dr. W. D. Strong, with the Smithsonian expedition in northeastern Honduras, was returning from a muleback and airplane reconnaissance of the interior between Trujillo and Tegucigalpa. The party returned to Trujillo on July 7, having located a considerable number of important and hitherto unknown ruins of Chorotegan type on the overland traverse. Collections were packed and shipped from Puerto Castilla and Dr. Strong reported in Washington July 18.

From that date until December he was occupied in sorting and classifying the Honduras ethnological and archeological collections and commencing a report on the Bay Island reconnaissance. At the

same time work was resumed on the report dealing with the stratified archeological horizons excavated on Signal Butte the year before. On December 11, 1933, Dr. Strong left Washington to take charge of archeological excavations at Buena Vista Lake, Kern County, Calif., made possible by a grant from the Federal Civil Works Administration. This work lasted until March 30, 1934. The excavations yielded a mass of specimens and detailed stratigraphic data bearing on the prehistoric human occupation of the great southern valley of California. Winslow M. Walker, who acted as assistant director on the excavations, is preparing a report on this work.

Beside the main excavation work at Buena Vista Lake a series of week-end reconnaissance trips to the Cuyama Valley yielded information on the prehistory of the eastern Chumash. A large burial ground and several village sites were excavated. The prehistoric house type in this border area seems to have been a round or ovoid earth-lodge, with from two to four central posts and no entrance passage. One house of this sort, early historic in time, had a flue up one side, reminiscent of Pueblo house types. At the close of the C. W. A. excavations a small party, under Dr. Strong's direction, made a survey of caves and village sites in the Santa Barbara Mountains west of the Cuyama Valley, and in the Hurricane Deck region of the Sisquoc River. Considerable perishable material from caves, data on a number of village sites, and some interesting pictographs were obtained on this trip. The culture of the eastern Chumash, as revealed by these valley and mountain sites, seems to have been intermediate between that of the coastal Chumash and Island Shoshonean culture and that of the Lake Yokuts. Particularly interesting is the fact that the eastern Chumash cultural remains are particularly close to those recovered from the older of the two kitchen middens excavated on Buena Vista Lake.

Dr. Strong returned to Washington May 1, 1934, and resumed work on the Signal Butte and Bay Island archeological reports.

Winslow M. Walker, associate anthropologist, unable to resume field researches because of the provisions of the Economy Act, instead devoted his time to a systematic examination and classification of the manuscript material collected by the late Dr. Cyrus Thomas relating to Indian mounds. These notes and reports were then refiled according to geographical location in the manuscript division. Some unpublished notes belonging to the late James Mooney were also found which contained data about archeological sites in various parts of the Cherokee country, and these together with a series of maps prepared by Mr. Mooney in the field were revised with the helpful

assistance of Mrs. Mooney, and made available for the use of any students interested in that section of the Southeast.

About the middle of December 1933 Mr. Walker left Washington to assist Dr. Strong in the direction of an archeological excavation project near Taft, Calif., made possible by a grant from the Federal Civil Works Administration. The site chosen consisted of two large shellmounds on the shore of Buena Vista Lake, known to the early Spanish explorers as the Yokuts village of Tulamniu. These mounds and a portion of the adjoining hill tops were made the object of systematic excavations lasting until the end of March 1934, employing a large number of men taken from the local relief rolls, as well as a number of experienced students from the University of California, and a staff of technical specialists. As a result a large amount of information was obtained about the construction and occupation of the shellmounds and the burial places of some 600 of their former inhabitants, and about 4,500 specimens were collected illustrating their material culture. Indications are that the inhabitants of the later mound are closely related in culture to the shellmound builders of the San Francisco Bay region, some of whom may have worked their way up the San Joaquin Valley, until they appeared in historic times as the lake tribes of the Southern Yokuts.

Following the closing of the C. W. A. work early in April, Mr. Walker also accompanied Dr. Strong on a 2-weeks' packing trip into the Santa Barbara Mountains mentioned above.

Mr. Walker returned to Washington the latter part of April and has since been engaged in the classification and study of the material collected in preparation for a report on the ancient Yokuts village site of Tulamniu.

During the fiscal year ending June 30, 1934, J. N. B. Hewitt, ethnologist, was engaged in office work. The time was devoted to the revision and literal and free translation of native texts in the Mohawk, the Cayuga, and the Onondaga languages, relating not only to the several institutions of the League of the Iroquois, but also to the traditional accounts of the events leading to its establishment, with traditional biographies of the founders and their antagonists, and also those relating to the legendary origin and development of the Wind or Disease Gods and as well those relating to the Plant or Vegetable Gods.

In the writings of many historians of the tribes of the Iroquois, there is a constant occurrence of the terms "elder" brothers, tribes, and nations, and "younger" brothers, tribes, and nations. These phrases have often been employed to show the tribal or racial descent of one Iroquois Tribe or people from another. Mr. Hewitt was able to demonstrate that the eldership or juniorship of tribes or nations

or political brothers among the Iroquois peoples has quite a different signification, these terms being courteous forms of address of an institutional nature, which bars completely the historical inferences or deductions so frequently made from them.

Mr. Hewitt was also enabled as a result of his studies to assign to their proper place and function the seven wampum strings utilized by the Iroquois in the Farewell Chant of the Condolence and Installation Convocation of the League of the Iroquois.

As the representative of the Smithsonian Institution on the United States Geographic Board and as a member of its executive committee Mr. Hewitt attended 10 regular and 4 special meetings of the Board and also 10 regular and 6 special meetings of the executive committee. On April 17, 1934, the President, by Executive order, abolished the United States Geographic Board, transferring its paid personnel of three members to the Interior Department, with the records and other property of the Board.

EDITORIAL WORK AND PUBLICATIONS

The editing of the publications of the Bureau was continued through the year by Stanley Searles, editor. The following publications were issued during the year ended June 30, 1934:

Forty-eighth Annual Report. Accompanying paper: General index, annual reports of the Bureau of American Ethnology, vols. 1-48 (Bonnerjea). v, 1,221 pp.

Fiftieth Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1932-33. 7 pp.

Publications distributed totaled 14,761.

LIBRARY

The reference library has continued under the care of Miss Ella Leary, librarian. The library consists of 30,701 volumes, about 17,095 pamphlets, and several thousand unbound periodicals. During the year 310 books were accessioned, of which 34 were acquired by purchase, the remainder being received through gift and exchange; also 102 pamphlets and 3,130 serials, chiefly the publications of learned societies, were received and recorded. The cataloging kept pace with the new accessions, and some progress was made in cataloging ethnologic and related articles in the earlier serials, 3,840 cards being added to the catalog. A considerable amount of reference work was done in the usual course of the library's service to investigators and students, both those in the Smithsonian Institution and others.

ILLUSTRATIONS

Following is a summary of work accomplished by E. G. Cassedy, illustrator, for the Bureau.

Water-color drawings	71
Line drawings	64
Stipple drawings	50
Wash drawings	4
Crayon drawings	1
Graphs	38
Maps	13
Lettering jobs	206
Layouts—sizing, lettering, and assembling	119
Retouched drawings	35
Tracings	2
Retouched photos	8
Restored negatives	8

COLLECTIONS

Accession number	
123372.	Skeletal material from a burial site near Sarasota, Fla. (1 specimen).
125140.	Archeological material from various sites in Louisiana, Georgia, and Mississippi, collected by W. M. Walker during the fall of 1932 (63 specimens).
125392.	Archeological and human skeletal remains, also some bird bones and four incomplete dog skeletons, collected in Arizona by Dr. F. H. H. Roberts, Jr., during the seasons of 1931 and 1932 (662 specimens).
126434.	Ethnological material from the Sumu and Miskito Indians collected by Dr. W. D. Strong while on a recent expedition to Honduras, also some natural history specimens (43 specimens).
128084.	Ethnological specimens from Australia and Papua presented to the Bureau by Joel H. DuBose (13 specimens).
129974.	Archeological and skeletal material collected by F. M. Setzler from August 20 to November 1, 1933, from mounds and village sites within the Marksville Works, near Marksville, La. (1,772 specimens).

MISCELLANEOUS

During the course of the year information was furnished by members of the Bureau staff in reply to numerous inquiries concerning the North American Indians, both past and present, and the Mexican peoples of the prehistoric and early historic periods. Various specimens sent to the Bureau were identified and data on them furnished for their owners.

Personnel.—Miss Marion Illig, junior stenographer, resigned on December 11, 1933.

Miss Edna Butterbrodt was appointed junior stenographer on June 1, 1934.

Respectfully submitted.

M. W. STIRLING, *Chief.*

Dr. C. G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 5

REPORT ON THE INTERNATIONAL EXCHANGE SERVICE

SIR: I have the honor to submit the following report on the operations of the International Exchange Service during the fiscal year ended June 30, 1934:

Congress appropriated \$39,054 for the International Exchange Service, \$38,500 of which was included in the regular appropriation act and \$554 in a deficiency act, the latter being for the purpose of restoring on February 1, 1934, 5 percent of the 15-percent economy reduction in salaries. The above appropriation is a decrease of \$2,571 from the actual amount expended for the service during the previous year. The repayments from departmental and other establishments aggregated \$3,805.27, a decrease of \$1,423, making the total resources available for conducting the service during the year \$42,859.27.

The number of packages that passed through the service during the year was 675,980, a decrease of 44,229. These packages weighed a total of 624,741 pounds, a decrease of 9,966 pounds.

The table below gives the number and weight of the packages arranged under certain classifications.

	Packages		Weight	
	Sent	Received	Sent	Received
			<i>Pounds</i>	<i>Pounds</i>
United States parliamentary documents sent abroad.....	341, 520		99, 852	
Publications received in return for parliamentary documents.....		9, 132		27, 724
United States departmental documents sent abroad.....	100, 019		123, 597	
Publications received in return for departmental documents.....		7, 418		27, 983
Miscellaneous scientific and literary publications sent abroad.....	162, 924		224, 665	
Miscellaneous scientific and literary publications received from abroad for distribution in the United States.....		54, 967		120, 920
Total.....	604, 463	71, 517	448, 114	176, 627
Grand total all packages handled.....	675,980		624,741	

The total number of boxes shipped abroad was 2,342, a decrease of 346. Of these boxes, 441 contained full sets of United States official documents for authorized foreign depositories and the remainder (1,901) were filled with publications for miscellaneous establishments and individuals. The number of packages sent abroad by mail was 57,359, a decrease of 22,271.

As stated in a previous report, the clearance of consignments arriving at the port of New York for the Smithsonian Institution was attended to from 1850 to July 1, 1923, by an official in the United States Customhouse. On the latter date the work was taken over by the Coordinator of the Second Area in New York City. The Office of the Coordinator subsequently having been abolished, the Institution appointed its own agent August 1, 1933. On April 1, 1934, the Smithsonian Agency in New York was discontinued and the duties were assumed by the United States Government Despatch Agent. Foreign consignments intended for the Institution and its branches therefore now should be addressed as follows:

Smithsonian Institution,
Washington, D. C.
c/o United States Despatch Agent,
45 Broadway,
New York, U. S. A.

Vittorio Benedetti, who for many years had ably served the Royal Italian Office of International Exchanges in Rome, was reinstated in July 1929, after a separation of 3 years, as chief of that office. In July 1933 he advised the Institution that, having passed the age limit, he had been retired. The service rendered by Mr. Benedetti in promoting the cultural relations between Italy and the United States is inestimable.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

The total number of sets of United States official publications sent to foreign depositories is 112, of which 62 are full and 50 partial. A complete list of the depositories is given in the report for 1931.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

The number of foreign legislative bodies and other governmental establishments to which the Congressional Record is forwarded under the terms of the convention for the immediate exchange of the official journal is 104. A list of the States taking part in this immediate exchange, together with the names of the establishments to which the Record is mailed, will be found in the report for 1931.

FOREIGN EXCHANGE AGENCIES

The Government of New Zealand advised the Institution under date of June 1 that the Exchange Agency for that country had been changed from the Dominion Museum to the General Assembly Library in Wellington.

The Chinese Bureau of International Exchange, which has been conducted under the direction of the Academia Sinica in Shanghai since 1930, was placed under the National Central Library in Nanking on July 1, 1934.

There is given below a list of the agencies abroad through which the distribution of exchanges is effected. Many of the agencies forward consignments to the Institution for distribution in the United States.

LIST OF EXCHANGE AGENCIES

ALGERIA, via France.

ANGOLA, via Portugal.

ARGENTINA: Comisión Protectora de Bibliotecas Populares, Calle Callao 1540, Buenos Aires.

AUSTRIA: Internationale Austauschstelle, National-Bibliothek, Augustinerbastei 6, Wien, I.

AZORES, via Portugal.

BELGIUM: Service Belge des Échanges Internationaux, Bibliothèque Royale de Belgique, Rue du Musée, 4, Bruxelles.

BOLIVIA: Oficina Nacional de Estadística, La Paz.

BRAZIL: Serviço de Permutações Internacionais, Bibliotheca Nacional, Rio de Janeiro.

BRITISH GUIANA: Royal Agricultural and Commercial Society, Georgetown.

BRITISH HONDURAS: Colonial Secretary, Belize.

BULGARIA: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.

CANADA: Sent by mail.

CANARY ISLANDS, via Spain.

CHILE: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.

CHINA: Bureau of International Exchange, National Central Library, Nanking.

COLOMBIA: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogotá.

COSTA RICA: Oficina de Depósito y Canje Internacional de Publicaciones, San José.

CUBA: Sent by mail.

CZECHOSLOVAKIA: Service Tchécoslovaque des Échanges Internationaux, Bibliothèque de l'Assemblée Nationale, Prague 1-79.

DANZIG: Amt für den Internationalen Schriftenaustausch der Freien Stadt Danzig, Stadtbibliothek, Danzig.

DENMARK: Service Danois des Échanges Internationaux, Kongelige Danske Videnskabernes Selskab, Dantes Plads, 35, Copenhagen V.

DUTCH GUIANA: Surinaamsche Koloniale Bibliotheek, Paramaribo.

ECUADOR: Ministerio de Relaciones Exteriores, Quito.

EGYPT: Government Press, Publications Office, Bulaq, Cairo.

ESTONIA: Riigiraamatukogu (State Library), Tallinn (Reval).

FINLAND: Delegation of the Scientific Societies of Finland, Kasärngatan 24, Helsingfors.

FRANCE: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.

GERMANY: Amerika-Institut, Universitätstrasse 8, Berlin, NW. 7.

GREAT BRITAIN AND IRELAND: Messrs. Wheldon & Wesley, 2, 3, and 4 Arthur Street, New Oxford Street, London, W. C. 2.

GREECE: Bibliothèque Nationale, Athens.

GREENLAND, via Denmark.

GUATEMALA: Instituto Nacional de Varones, Guatemala.

HAITI: Secrétaire d'État des Relations Extérieures, Port-au-Prince.

HONDURAS: Biblioteca Nacional, Tegucigalpa.

HUNGARY: Hungarian Libraries Board, Ferenciektere 5, Budapest, IV.

ICELAND, via Denmark.

INDIA: Superintendent of Government Printing and Stationery, Bombay.

ITALY: R. Ufficio degli Scambi Internazionali, Ministero dell' Educazione Nazionale, Viale del Re, Rome.

JAMAICA: Institute of Jamaica, Kingston.

JAPAN: Imperial Library of Japan, Uyeno Park, Tokyo.

JAVA, via Netherlands.

KOREA: Sent by mail.

LATVIA: Service des Échanges Internationaux, Bibliothèque d'État de Lettonie, Riga.

LIBERIA: Bureau of Exchanges, Department of State, Monrovia.

LITHUANIA: Sent by mail.

LOURENÇO MARQUEZ, via Portugal.

LUXEMBURG, via Belgium.

MADAGASCAR, via France.

MADEIRA, via Portugal.

MEXICO: Sent by mail.

MOZAMBIQUE, via Portugal.

NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.

NEW SOUTH WALES: Public Library of New South Wales, Sydney.

NEW ZEALAND: General Assembly Library, Wellington.

NICARAGUA: Ministerio de Relaciones Exteriores, Managua.

NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.

PALESTINE: Hebrew University Library, Jerusalem.

PANAMA: Sent by mail.

PARAGUAY: Sección Canje Internacional de Publicaciones del Ministerio de Relaciones Exteriores, Estrella 563, Asunción.

PERU: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.

POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Ul. Rakowiecka 6, Warsaw.

PORTUGAL: Secção de Trocas Internacionais, Biblioteca Nacional, Lisboa.

QUEENSLAND: Bureau of Exchanges of International Publications, Chief Secretary's Office, Brisbane.

RUMANIA: Bureau des Échanges Internationaux, Institut Météorologique Central, Bucharest.

SALVADOR: Ministerio de Relaciones Exteriores, San Salvador.

SIAM: Department of Foreign Affairs, Bangkok.

SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.

SPAIN: Servicio de Cambio Internacional de Publicaciones, Paseo de Recoletos 20, bajo derecha, Madrid.

SUMATRA, via Netherlands.

SWEDEN: Kongliga Svenska Vetenskaps Akademien, Stockholm.

SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Berne.

SYRIA: American University of Beirut.

TASMANIA: Secretary to the Premier, Hobart.

TRINIDAD: Royal Victoria Institute of Trinidad and Tobago, Port-of-Spain.

TUNIS, via France.

TURKEY: Robert College, Istanbul.

UNION OF SOUTH AFRICA: The Government Printer, Box 373, Pretoria, Transvaal.

UNION OF SOVIET SOCIALIST REPUBLICS: Academy of Sciences, Birzhevaya L. 1, Leningrad V. O.

URUGUAY: Oficina de Canje Internacional de Publicaciones, Ministerio de Relaciones Exteriores, Montevideo.

VENEZUELA: Biblioteca Nacional, Caracas.

VICTORIA: Public Library of Victoria, Melbourne.

WESTERN AUSTRALIA: Public Library of Western Australia, Perth.

YUGOSLAVIA: Ministère des Affaires Étrangères, Belgrade.

Respectfully submitted.

C. W. SHOEMAKER,
Chief Clerk.

Dr. C. G. ABBOT,
Secretary, Smithsonian Institution.

APPENDIX 6

REPORT OF THE NATIONAL ZOOLOGICAL PARK

SIR: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ended June 30, 1934.

The regular appropriation made by Congress for the maintenance of the park was \$180,000. There was a reduction, mainly impoundage for positions vacant, of \$4,778. The total expenditures for the year were about \$175,200.

ACCESSIONS

Gifts.—A number of important gifts during the year have enriched the collection appreciably. W. E. Buck, of Camden, N. J., presented an electric catfish. From the Mount Vernon Ladies Association, through Colonel Dodge, were received a pair of Virginia deer. William LaVarre, of New York City, presented a pair of rare white tayra cats.

From the Ringling Brothers-Barnum & Bailey Circus was received the Indian elephant "Babe", a famous animal that had traveled with the circus for 51 years. She was presented at the afternoon performance on May 16, through Samuel W. Gumpertz and Robert Ringling.

Dr. Knowles Ryerson, of the Department of Agriculture, collected in Puerto Rico and presented a specimen of the rare and attractive *Anolis cuvieri*.

DONORS AND THEIR GIFTS

Paul Achstetter and Hugh Claggett, Washington, D. C., 4 blue-tailed skinks, spiny lizard.

Messrs. Acton and Williams, Riverdale Fire Department, Riverdale, Md., alligator.

A. M. Agelasto, Washington, D. C., 2 spotted gourami.

R. M. Allen and Ernest C. Weise, Washington, D. C., tarantula, scorpion.

Atlantic & Pacific Tea Co., Store No. 310, Washington, D. C., common boa.

C. C. Baker, Washington, D. C., tarantula.

Howard Ball, Washington, D. C., pintail.

H. Walter Barrows, Takoma Park, Md., green snake.

Pierce Beach, Silver Spring, Md., opossum.

Otto Benesh, Washington, D. C., blacksnake.

Dean F. Berry, Orlando, Fla., coral snake.

D. G. Blake, Washington, D. C., opossum.

- W. F. Boldridge, Rixeyville, Va., 2 barn owls.
Mrs. J. S. C. Boswell, Alexandria, Va., king snake.
H. A. Bowie, Washington, D. C., alligator.
Mrs. James Broadmore, Washington, D. C., yellow-fronted parrot.
Warren Buck, Camden, N. J., electric catfish.
Dr. Charles E. Burt, Winfield, Kansas, 5 snapping turtles, 20 box tortoises, 37 painted turtles, 34 musk turtles, 4 six-lined race runners, hog-nosed snake, golden eagle.
E. A. Candidus, Morsemere, N. J., armored catfish.
V. F. Cannon, Washington, D. C., bald eagle.
F. G. Carnochan, New York, N. Y., 2 wood turtles.
Claude T. Carpenter, Washington, D. C., diamond-back rattlesnake.
Carlyle Carr, Biological Survey, Gainesville, Fla., 2 coral snakes, horn snake.
Mrs. H. W. Clark, Washington, D. C., 2 Pekin ducks, 2 box tortoises.
J. B. Clark, Washington, D. C., alligator.
O. G. Clay, Washington, D. C., ring-necked pheasant.
Miss Myrabelle Clow, Washington, D. C., red fox.
W. F. Cochran, Washington, D. C., screech owl.
E. S. Cook, Washington, D. C., horned toad.
Miss Isabelle Cooke, Washington, D. C., pilot snake.
J. T. Cooke, Athens, Tenn., 2 ospreys.
"Buzzie" and "Sistie" Dall, Washington, D. C., alligator.
Malcolm Davis, Washington, D. C., 2 grass paroquets.
Charles F. Denley, Glenmont, Md., 2 ring-necked pheasants.
G. F. Dennis, Cherrydale, Va., broad-winged hawk.
Colonel Dodge, Mount Vernon Estate, Va., 2 Virginia deer.
Charles E. Eaton, Washington, D. C., red salamander.
R. K. Enders, Swarthmore College, Pa., 3 small red rodents.
Harry Feldinan, Washington, D. C., pied-bill grebe.
Mrs. A. E. Foot, Washington, D. C., 3 guinea pigs.
R. C. Frame, Washington, D. C., capuchin monkey.
Mrs. L. C. Frank, Chevy Chase, Md., 2 flying squirrels.
George Freeman, Bluemont, Va., great horned owl.
Langdon and Garland Fulton, Washington, D. C., burrowing owl.
Mrs. H. P. Gantt, Fort Hoyle, Md., banded rattlesnake.
Paul Hagdeson, Washington, D. C., woodchuck.
H. P. Hansberger, Washington, D. C., 3 copperheads.
Charles A. Harbaugh, Washington, D. C., blue jay.
G. A. Harlow, Culpeper, Va., 2 raccoons.
Dr. W. T. Harrison, National Institute of Health, Washington, D. C., 2 green guenons.
B. C. Hayes, Washington, D. C., American barn owl.
N. S. Henrique, Habana, Cuba, Cuban boa.
R. Hess, Washington, D. C., ring-necked pheasant.
Roy Holmes, St. Petersburg, Fla., spider monkey.
T. B. Hopper, Washington, D. C., canary.
Mrs. Horton, Washington, D. C., Cuban parrot.
Miss Nan Hughes, Washington, D. C., double yellow-head parrot.
Mrs. Alice Jenks, Washington, D. C., yellow-naped parrot, double yellow-head parrot.
W. Jennier, Cincinnati, Ohio, 30 horned lizards.
Vernon O. Kanable, Clarendon, Va., copperhead.
Mrs. Shunichi Kase, Washington, D. C., barred owl.

- Mrs. Hazel Kenmeser, Washington, D. C., Pekin duck.
 Mrs. Franklin Kenworthy, Purcellville, Va., white-crowned seed eater.
 R. R. Klotz, Washington, D. C., broad-winged hawk.
 Frank Kothe, Washington, D. C., sparrowhawk.
 Warren Krumke, Washington, D. C., green snake.
 William LaVarre, New York, N. Y., 2 white tayra.
 F. Leonard, Washington, D. C., common turkey.
 Mrs. Jerome Lightfoot, Washington, D. C., albino bullfrog.
 David Lynn, Washington, D. C., ring-necked pheasant, diamond-back terrapin.
 James and John Magill, Athens, Tenn., 2 turkey vultures.
 George E. Malamphy, Georgetown, S. C., water moccasin, 2 copperheads, hog-nose snake, red racer.
 Mr. and Mrs. C. Manuel, Fairfax, Va., American black bear.
 J. J. Marcotte, Chevy Chase, Md., golden pheasant, 6 ring-necked pheasants.
 G. F. Marshall, Washington, D. C., Cuban parrot.
 W. B. McCann, Washington, D. C., skunk.
 Dr. Robert C. McCullough, Washington, D. C., red-shouldered hawk.
 Henry J. McDermitt, Takoma Park, Md., great horned owl.
 E. A. McIlhenny, Avery Island, La., 6 blue geese, 4 lesser snow geese.
 D. F. Miller and Tom Rowell, Washington, D. C., watersnake.
 Miss Evelyn H. Miller, Washington, D. C., snapping turtle.
 Peter Mills, Miami, Fla., gopher turtle.
 Mitloff's Market, Washington, D. C., common boa.
 J. Mock, Washington, D. C., Reeve's pheasant.
 Dr. Carlton Morse, Watertown, Mass., mynah.
 G. C. Moss, Newport News, Va., hog-nosed snake.
 Miss Vera L. Munday, Silver Spring, Md., grass paroquet, canary.
 J. R. Page, Greensboro, N. C., chicken snake.
 Nelson and Robert Peach, Mitchellville, Md., sparrowhawk.
 Petty and Jane Perkins, Washington, D. C., 2 Pekin ducks.
 G. F. Pollock, Skyland, Va., timber rattlesnake.
 Harry B. Ragland, Washington, D. C., groundhog.
 John L. Reh, Washington, D. C., alligator.
 Loyd Reichard, Waynesboro, Pa., Florida pine snake, indigo snake, horn snake, coral snake, grass snake or legless lizard.
 A. G. Rhinehart, Washington, D. C., 3 horned lizards.
 Ringling Bros.-Barnum & Bailey Circus, Indian elephant.
 Norman Rovzar, Washington, D. C., garter snake.
 Louis Ruhe, Inc., New York City, 5 mangrove snakes.
 Mrs. Russell, Takoma Park, Md., opossum.
 K. A. Ryerson, Department of Agriculture, Washington, D. C., spiny-tailed anolis.
 Edward S. Schmid, Washington, D. C., 7 magpies, 2 marmosets, ostrich.
 Mrs. Schribner, Washington, D. C., ring-necked pheasant.
 Wilson Smith, Washington, D. C., vinegarone or whip scorpion.
 R. E. Stadelman, Tela, Honduras, 12 *Lepidophyma* lizards.
 Charles Stebbins, Washington, D. C., gray fox.
 Miss Stewart, Washington, D. C., 2 grass paroquets.
 A. J. Stout, Washington, D. C., red-crowned parrot.
 Andrew Tenley, Washington, D. C., raccoon.
 L. E. Thrift, Woodbridge, Va., barred owl.
 Dr. Tytus Ulke, Washington, D. C., tree frog.

United States National Museum, Washington, D. C., hybrid canary.
 Guy van Dyne, St. Petersburg, Fla., Florida diamond-back rattlesnake.
 Robert Wallace, Washington, D. C., red-tailed hawk, Florida king snake, 3 water snakes, garter snake, blacksnake.
 Lester Walters, Washington, D. C., barn owl.
 Mrs. Charles Warren, Washington, D. C., orange-checked wax-bill, Swainson's bronzed mannikin.
 H. F. Watson, Washington, D. C., alligator.
 E. H. Wood, Parksville, S. C., 61 Florida cooters, 10 painted turtles.
 W. B. Wood, Department of Agriculture, Washington, D. C., 2 horned lizards.
 Maj. G. R. Young, Portsmouth, Va., bald eagle.
 Source unknown: 3 Reeve's pheasants.

Exchanges.—A concave-casque hornbill was obtained from Louis Ruhe, Inc., New York City. From the South Australian Acclimatization Park, Adelaide, Australia, were received an elegant paroquet, 2 Bourke's paroquets, 2 Cape Barren geese, a blue-tongued lizard, a monitor, and 2 vulpine phalangers.

Purchases.—Important purchases during the year at prices that made them practically gifts were 3 white-lipped peccaries from R. E. Stadelman, Tela, Honduras; the rare Komodo dragon from Lawrence Griswold and William Harkness, New York City; and a maned wolf, collected in South America by Dr. S. A. Dameron, Baltimore, Md. There was also purchased an aard-vark and a gerenuk, the first of their kind ever exhibited in the park.

Births.—There were 40 mammals born and 19 birds hatched in the park during the year. These include the following:

MAMMALS

Scientific name	Common name	No.
<i>Ammotragus lervia</i>	Aoudad.....	1
<i>Axis axis</i>	Axis deer.....	3
<i>Bison bison</i>	American bison.....	2
<i>Bubalus bubalis</i>	Indian buffalo.....	1
<i>Cervus duvauceli</i>	Barasingha deer.....	1
<i>Dama dama</i>	Fallow deer.....	5
<i>Dolichotis patagonica</i>	Patagonian cavy.....	2
<i>Dolichotis salinicola</i>	Dwarf cavy.....	4
<i>Equus quagga chapmani</i>	Chapman's zebra.....	1
<i>Felis onca</i>	Jaguar.....	2
<i>Hemitragus jemlahicus</i>	Tahr.....	2
<i>Hyelaphus porcinus</i>	Hog deer.....	1
<i>Lama glama</i>	Llama.....	1
<i>Macropus rufus</i>	Great red kangaroo.....	1
<i>Odocoileus virginianus</i>	Virginia deer.....	3
<i>Ovis canadensis</i>	Rocky Mountain sheep.....	1
<i>Ovis europaeus</i>	Mouflon.....	2
<i>Sika nippon</i>	Japanese deer.....	6
<i>Ursus gyas</i>	Alaska Peninsula bear.....	1

BIRDS

<i>Branta canadensis</i>	Canada goose.....	10
<i>Gennaeus swinhoei</i>	Swinhoe's pheasant.....	1
<i>Guara alba</i> x <i>G. rubra</i>	Ibis (hybrid).....	1
<i>Pavo cristatus</i>	Peafowl.....	2
<i>Taeniopygia castanotis</i>	Zebra finch.....	5

REMOVALS

Deaths.—A large anaconda which had been in the collection since July 25, 1917, died October 10, 1933, from a tumor. A South African buffalo and an inyala died during the year. The inyala was the only specimen of its kind on exhibit in the United States.

ANIMALS IN COLLECTION THAT HAD NOT PREVIOUSLY BEEN EXHIBITED

MAMMALS

Scientific name	Common name
<i>Chrysocyon jubata</i>	Maned wolf.
<i>Litocranius walleri</i>	Gerenuk, or giraffe gazelle.
<i>Orycteropus</i> sp.....	Aard-vark.
<i>Presbytes obscura</i>	Dusky or crested langur.

BIRDS

<i>Neophema bourki</i>	Bourke's paroquet.
<i>Spheniscus demersus</i>	Jackass penguin.

REPTILES

<i>Anolis cuvieri</i>	Spiny or saw-tailed anolis.
<i>Varanus komodoensis</i>	Komodo dragon.

Statement of the collection

[Accessions]

	Presented	Born	Received in exchange	Purchased	On deposit	Total
Mammals.....	28	39	6	25	6	104
Birds.....	81	19	23	72	6	201
Reptiles.....	142		2	222	25	391
Amphibians.....	3			13		16
Fishes.....	4			20		24
Arachnids.....	5					5
Insects.....		30				30
Crustaceans.....	1					1
Total.....	264	88	31	352	37	772

Summary

Animals on hand July 1, 1933.....	2,496
Accessions during the year.....	772

Total animals in collection during year.....	3,268
Removed from collection by death, exchange, and return of animals on deposit.....	1,030

In collection June 30, 1934.....	2,238
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Status of collection

	Species	Individuals		Species	Individuals
Mammals.....	172	495	Insects.....	1	40
Birds.....	328	1,028	Crustaceans.....	1	1
Reptiles.....	147	520	Mollusks.....	1	5
Amphibians.....	24	69			
Fishes.....	31	76	Total.....	707	2,238
Arachnids.....	2	4			

There are fewer individuals in the list of the collection than last year. Because of the crowded conditions no attempt has been made to replace losses in certain groups that cannot be properly exhibited, and numbers of fish, amphibia, and other very transient individuals have not been listed.

The quality of the collection, however, is greatly improved, and the park is exhibiting an unusual number of rare and interesting species.

Visitors

July.....	262,300	March.....	70,200
August.....	267,825	April.....	999,496
September.....	270,900	May.....	286,800
October.....	268,400	June.....	243,020
November.....	103,600		
December.....	99,600	Total visitors for	
January.....	84,750	year.....	2,978,041
February.....	21,150		

The attendance of organizations, mainly classes of students, of which there is definite record, was 34,445 from 586 different schools in 20 States and the District of Columbia, as follows:

State	Number of persons	Number of parties	State	Number of persons	Number of parties
Connecticut.....	232	4	New Jersey.....	2,810	42
Delaware.....	263	7	New York.....	2,798	21
District of Columbia.....	8,173	151	North Carolina.....	552	14
Georgia.....	26	1	North Dakota.....	43	1
Illinois.....	106	1	Ohio.....	305	7
Maine.....	155	3	Pennsylvania.....	7,305	125
Maryland.....	6,773	106	South Carolina.....	83	3
Massachusetts.....	229	6	Virginia.....	3,699	80
Michigan.....	287	4	West Virginia.....	420	8
Missouri.....	164	1			
New Hampshire.....	22	1	Total.....	34,445	586

Observations of the numbers of automobiles from the District of Columbia and the different States and countries has led to the taking of a census each day of the cars actually parked in the park at one time. From a total of about 35,000 cars it has been ascertained that approximately 50 percent are from the District of Columbia, the remainder including cars from every State in the Union, besides several from each of the following possessions and countries: Alaska, Canal Zone, Hawaii, Canada, and Panama.

IMPROVEMENTS

No funds were available for the construction of buildings, but for the period July 1 to November 21, minor repairs to structures, painting, repairing walks, improving the grounds by needed clearing, planting, making fills, and sodding, were carried out with labor furnished by the Work Planning and Job Assignment Committee of the District.

Beginning in November activities were considerably expanded when the C. W. A. took over the supplying of labor, both skilled and unskilled, and some money was made available for the purchase of materials to be used on the projects. This permitted the undertaking of a considerable volume of urgently needed work which could not be previously attempted. The more outstanding repairs and improvements undertaken with C. W. A. materials are as follows:

Project no.

1. Construction of brick smokestack at bird house to replace the metal one that was in very bad condition.
2. Replacing old and unsatisfactory frame structure by a series of stone shelters and new fence for antelope and wild sheep.
3. Construction of large cage at bird house to house Andean condors and lammergeyers.
4. Grading of the wild-horse exhibition area and construction of shelters and paddocks.
5. Replacing an unsafe wooden floor in the lion house with a concrete-terrazzo floor.
6. Putting brick foundation under warehouse no. 2 to replace a badly decayed wood foundation.
8. Laying 6-inch water main into the Director's office and installing fire hydrant near office.
11. Construction of one-fourth mile of 18-foot service road from the silver gull cage to the bird house.
12. Grading, sodding, and protecting banks that were eroding, and otherwise improving the grounds.
13. Revising of a topographic map of the National Zoological Park.
15. Arranging and indexing file of blueprints and maps in Director's office.
16. Cataloging and arranging Zoo library.
18. Completing preparations of plans and specifications for a small mammal house.
20. Revision of plans for the completion of the bird house.
30. Minor construction, improvements, and repairs, consisting of painting, repairing, improving or replacing minor buildings, cages, fences, pools, pipes, drainage and electric lines, etc., and resurfacing, improving and extending roads, walks, trails, bridle paths, and grounds.

Bad winter weather conditions seriously delayed the progress of the work. This left many of the jobs incomplete when the work suddenly terminated March 31, 1934. However, from April 1 to June 30 a limited amount of unskilled labor was assigned under the Work Planning and Job Assignment Committee. During this period

efforts were devoted to the finishing up of the jobs that had been undertaken under the C. W. A. and on June 30 all had been completed or practically completed with the exception of the lion house floor, the mountain-sheep mountain, and a small stone house for hardy animals.

Much ground improvement work was carried on. In the spring the grounds improvement work was continued by the making of fills, siding banks that were eroding, planting of grass seed, shrubs, and trees, and a cleaning of the lawns of weeds that had become established over a long period of years and were doing serious damage.

Much still remains to be done in the way of repairs and small improvements such as the reroofing or rebuilding of small structures, replacement of paddock fences that are in bad condition, construction of pools, paddocks, and cages, and miscellaneous repairs.

All District officials with whom contact was had in the course of the C. W. A. and Emergency Relief operations have been most helpful and relations have been pleasant at all times, and to their splendid cooperation a large proportion of the success attained in the work can be attributed. At the close of the fiscal year it is the understanding that a limited amount of labor will continue to be available to the park, and the plans contemplate a continuance of similar activities to such extent as the character of labor and amount of materials available will permit.

Through the kind help of Capt. H. F. Clark and other District officials, steel was obtained from the Aqueduct Bridge that was being demolished, second-hand bricks from old buildings being razed, and new bricks from the Occoquan plant of the District. A number of trees and shrubs were acquired through the kindness of Clifford Lanham, superintendent of trees and parking.

NEEDS OF THE ZOO

These remain as in previous years. No important construction of exhibition buildings has been possible.

The park itself is second to none in natural beauty. The two good buildings, the bird house and the reptile house, are widely and favorably known throughout the United States and, in fact, among zoo enthusiasts throughout the world. The other buildings are quite as widely known and the subject of unfavorable criticism by all who have interest in and knowledge of zoological parks.

It has been shown that the number of visitors has greatly increased. They come from every State in the Union, and from throughout the world. It is felt that the interest in the National Zoo and the benefit derived from it by these visitors warrants the completion of the entire program that has been submitted year after year.

By comparison with work being done in other zoos we believe these requests to be entirely reasonable, considering the Zoo not only as a national institution but as one suitable for such a city as Washington, D. C.

During the present year the appropriation has been \$180,000. Nearly 3,000,000 persons have visited the Zoo. It can be seen that the cost per visitor is trivial. The one desire is to have exhibition quarters so that the animals may be properly housed and displayed.

Respectfully submitted.

W. M. MANN, *Director.*

Dr. C. G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 7

REPORT ON THE ASTROPHYSICAL OBSERVATORY

SIR: I have the honor to submit the following report on the activities of the Astrophysical Observatory for the fiscal year ending June 30, 1934:

This observatory comprises: (a) The central station at Washington where apparatus is made and standardized; where reports are computed, written, and published; where preparations for expeditions are made; and where a general oversight is maintained of the field stations. (b) A station on Mount Wilson near Pasadena, Calif., where brief expeditions for special researches go from time to time. (c) A station on Table Mountain near Swartout, Calif., where daily observations of the solar constant of radiation are carried on. (d) A similar solar-constant station on Mount Montezuma, near Calama, Chile. (e) A similar station on Mount St. Katherine near Mount Sinai, Egypt. These stations are supported principally by annual Government appropriations, but in a considerable part by private funds.

WORK AT WASHINGTON

Messrs. Aldrich and Fowle and Mrs. Bond completed the statistical analysis of the observations made at Mount Montezuma since 1932. Thereby an improved method of reduction was worked up, which is now in regular use at Montezuma. Increased accuracy over the former method has resulted.

Mr. Fowle's revision of the Smithsonian Physical Tables has been published as the Eighth Revised Edition, greatly enlarged. Much favorable comment has come regarding it.

Director Abbot, with the assistance of Mrs. Bond, has continued the study of solar variation with reference to weather changes. Several papers thereon have been published.

With the assistance of A. Kramer, mechanic, and Messrs. Clark and McAlister of the Division of Radiation and Organisms, Messrs. Abbot and Aldrich prepared an expedition to Mount Wilson for the summer of 1934. The accomplishments of this successful expedition will be reported in 1935.

WORK IN THE FIELD

The station at Table Mountain reported daily by telegraph the solar-constant values obtained. These were communicated to Science Service for daily international broadcasting.

The station at Mount Montezuma made daily observations. They were not communicated daily, as formerly, until after the revised method above referred to was finished. This was not until after the close of the period covered by this report.

By the generosity of John A. Roebling, a new station on Mount St. Katherine near Mount Sinai, Egypt, was occupied. By cooperation of His Eminence the Archbishop Porphyrio III, the buildings, consisting of the observatory and a nearby dwelling and shop, and the approaches thereto over the excessively rough mountain were built by the St. Katherine Monastery. The monastery also undertakes to carry forward the supplies by camel train from Tor on the Red Sea.

The station is at an elevation of about 8,500 feet in a wildly mountainous region, destitute of vegetation and almost destitute of rainfall. It is difficultly accessible. The staff comprises H. H. Zodtner, with wife and two infant children, and F. A. Greeley. Observations were begun in December 1933 and have proceeded regularly. It is yet too soon to be sure how satisfactory the meteorological conditions will prove, but while the station is not equal to Mount Montezuma, it is believed to be superior to Table Mountain in this respect.

PERSONNEL

No changes have occurred from last year's list, except that Wilson R. Maltby succeeded Walter Watson, Jr., as assistant at Mount Montezuma on June 23, 1933, Mr. Watson reporting as assistant at Table Mountain.

SUMMARY

A revised method of reduction of solar-constant observations has been completed and applied at Mount Montezuma, resulting in improved accuracy. The Eighth Revised Edition of the Smithsonian Physical Tables, prepared by Mr. Fowle and greatly enlarged over previous editions, has been published. Much progress has been made in the study of the relations of solar variation to the weather. Daily solar-constant values have been broadcast. A new solar-constant observatory has been established at Mount St. Katherine near Mount Sinai, Egypt.

Respectfully submitted.

C. G. ABBOT, *Director.*

The SECRETARY,
Smithsonian Institution.

APPENDIX 8

REPORT ON THE DIVISION OF RADIATION AND ORGANISMS

SIR: I have the honor to submit the following report on the activities of the Division of Radiation and Organisms during the year ending June 30, 1934:

The work of the year has been very fruitful. It was supported as heretofore largely by a special grant from the Research Corporation of New York. There has been no change in personnel excepting the resignation of Miss Virginia Stanley, typist secretary, and the substitution, part time, of Miss Ruth MacManus.

Most of the experiments of the Division are done with electric lights. Mr. Hoover continued measurements on the absorption of carbon dioxide from the air by wheat plants under the influence of radiation. Using the Christiansen filters prepared by Messrs. McAlister and Clark as described in last year's report, Mr. Hoover was able to grow wheat in rays comprising narrow bands of nearly homogeneous radiation of various wave lengths between the ultraviolet and the infrared spectral regions. These rays were of measured intensity; the temperature, humidity, and chemical food of the plants were standardized; and the absorption of carbon dioxide was recorded by automatic apparatus. The results obtained were checked by growth experiments under strictly monochromatic rays produced by the mercury arc.

As a result a well-determined curve of photosynthesis, rising from zero in the ultraviolet, reaching maxima at about 4400 and 6400 angstroms, and descending to zero in the infrared, has been determined.

Dr. McAlister assisted Mr. Hoover and the other members of the staff in many physical manipulations, standardizations, and measurements. He also, in cooperation with Dr. Wright, of the Department of Agriculture, carried through a long series of measurements on the effect of radiation on worm eggs. He also worked out for Director Abbot the elements of a set of Christiansen filters covering the region 3300 to 10300 angstroms for use in stellar spectrum measurements at Mount Wilson. With Dr. F. S. Brackett he made much progress in the development of powerful apparatus for visible and infrared absorption spectral investigations.

Dr. E. S. Johnston, besides having immediate charge of the Division, conducted growth experiments with special radiation on toma-

toes. He also repeated and published measurements on phototropism in oat coleoptiles. These measurements are of such extreme accuracy in indicating the relations of sensitiveness of bending to wave length that the curve seems to be accurate in much of its length to less than 2 percent. Dr. Johnston also carried through in the open sunlight a series of experiments to determine the influence on wheat of modifying the supply of carbon dioxide. The results are exceptionally striking and will form a paper in the Smithsonian Miscellaneous Collections.

Dr. Florence E. Meier continued experimental studies of the influence of different colored rays on the multiplication of the alga *Stichococcus bacillaris*. Further check experiments are contemplated. She published results on the lethal action of ultraviolet rays on *Chlorella vulgaris*.

L. B. Clark made up many valuable designs of glass and electrical appliances for all members of the staff and also for the staff of the Astrophysical Observatory. His technical skill and wise counsel in these fields were indispensable.

Dr. F. S. Brackett, part-time consulting physicist, made progress in preparing apparatus for absorption spectral investigations, and designed therefor very ingenious devices. Much of his time, however, was absorbed in the preparation of an important technical monograph on radiation measurements, to be published under the auspices of the National Research Council. Dr. Brackett's experience in such work makes this contribution of extreme value.

Respectfully submitted,

C. G. ABBOT, *Director*.

The SECRETARY,
Smithsonian Institution.

APPENDIX 9

REPORT ON THE LIBRARY

SIR: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1934.

THE LIBRARY

The various libraries of the Smithsonian, which have come into being one by one since 1846 to meet the developing needs of the Institution and its affiliated Government bureaus, comprise a library system of well over 800,000 volumes, pamphlets, and charts. Its chief unit is, of course, the Smithsonian deposit in the Library of Congress; next in size and importance are the libraries of the United States National Museum and the Bureau of American Ethnology. The other units are the libraries of the Astrophysical Observatory, Freer Gallery of Art, National Gallery of Art, National Zoological Park, the Langley aeronautical library, Smithsonian office library, radiation and organisms library, and the 35 working libraries in the offices of the curators of the National Museum. Together they form a cooperative system, with the deposit as the great central collection, which, while to some extent more or less general in character, is for the most part closely related to the special interests of the Institution and its branches.

CHANGES IN PERSONNEL

On July 1, 1933, Leonard C. Gunnell, formerly assistant in charge of the United States Bureau of the International Catalogue of Scientific Literature (discontinued on June 30, 1933) was made an assistant librarian and was assigned to certain bibliographical projects. Mrs. M. Landon Reed, who had been a clerk for some years in the correspondence division, retired the middle of the year, and her position was filled by the transfer of Miss Josephine A. McDevitt from the Bureau of the International Catalogue of Scientific Literature.

EXCHANGE OF PUBLICATIONS

The Smithsonian library has been built up partly—in the early days—by the operation of the copyright law, partly by purchase and gift, but chiefly by the exchange of the publications of the Institution and those of its official branches for the publications of other learned institutions and societies and for various scientific and technical journals. During the fiscal year just closed the library received

22,020 packages, each containing one or more publications. Of these, 20,044 came by mail and 1,976 through the International Exchange Service, which is administered by the Smithsonian. Especially generous sendings were received from the Académie Malgache, Tananarive; the Deutsche Gesellschaft der Wissenschaften und Künste für die Tschechoslowakische Republik, Prag; the Elisha Mitchell Scientific Society, Chapel Hill; the Fürstlich Jablonowskische Gesellschaft der Wissenschaften, Leipzig; the Historische-Antiquarische Gesellschaft, Basel; the Societatea de Stiinte din Cluj, Cluj; the Société Scientifique du Chili, Santiago; the Société Zoologique de France, Paris; the Société des Amis de l'Université de Strasbourg, Strasbourg; and the Wochenschrift für Aquarien und Terrarienkunde, Braunschweig. Four of these went far toward completing important sets in the Smithsonian deposit and six in the library of the National Museum. Among the exchange items were 7,776 dissertations from the universities of Basel, Berlin, Bern, Bonn, Breslau, Budapest, Cornell, Erlangen, Freiburg, Giessen, Greifswald, Halle, Heidelberg, Helsingfors, Jena, Johns Hopkins, Kiel, Königsberg, Köln, Leipzig, Liège, Lund, Marburg, Neuchâtel, Pennsylvania, Rostock, Strasbourg, Tübingen, Utrecht, Würzburg, and Zürich, the Academy of Freiberg, and technical schools at Berlin, Braunschweig, Dresden, Karlsruhe, and Zürich. The number of letters written by the library was 2,482, most of which had to do with its exchange activities, its reference work for outside correspondents, and its acknowledgment of gifts. It obtained 4,114 volumes and parts in response to special requests from the various libraries of the Institution. It entered into 238 new exchanges, more than one-half of which were in the interest of the libraries of the National Museum and National Gallery of Art. It may be added that most of these publications were obtained and most of the new exchanges arranged for without drawing further on the stock of Smithsonian publications. It should also be said in passing that steps were taken late in the year to increase this supply, as well as that of the National Museum, very materially when the library staff, in collaboration with members of the division of publications, sorted and sent back to stock thousands of pieces—many of them out of print—that had been returned as duplicates from libraries throughout the country. This is the second joint effort of the kind during the last 2 years and each has both added substantially to the publications available for exchange distribution and brought to light hundreds that were needed in the regular library sets.

GIFTS

The gifts were numerous. They included a set, in 15 folio volumes, of the *Raccolta di Documenti e Studi Pubblicati dalla R. Commissione Colombiana per Quarto Centenario dalla Scoperta dell'America*,

issued at Rome in 1892-96 under the auspices of the Ministry of Public Instruction, from Otto H. F. Vollbehr; *Algemeene en Byzondere Natuurlyke Historie* (1773), in 17 volumes, by Comte de Buffon, from Morris M. Green; *Cowboy Scrap Books*, in 3 volumes, by L. Fred Foster, from John H. Foster and Louise T. Foster Ramer; 22 books on cycling and the bicycling era in England and America, from Albert E. Schaaf; 19 publications on archeology, by Louis Speleers, from the author; *Journal of the American Osteopathic Association*, volumes 1-19, from G. H. Snow; *Journal of Osteopathy*, 179 volumes and parts, from H. E. Litton, editor; *The Birds of Tropical West Africa*, volume 3, by David Armitage Bannerman, from the Crown Agents for the Colonies; *Lectures, Selected Papers, Addresses*, by Cyrus Adler, from the author; *Teneriffe: An Astronomer's Experiment*, by C. Piazzzi Smyth, from John C. Bridwell; *Some Aeronautical Music from the Collection of Bella C. Landauer*, from Mrs. Landauer; *Harry Wearne: a Short Account of His Life and Work, with 63 Reproductions of His Designs in Full Color*, from Harry Wearne, Inc.; *Historic House Museums* (2 copies), from the American Association of Museums; *The Folger Shakespeare Library*, from the Trustees of Amherst College; *The Reconstruction of Tokyo* (2 copies), from Mayor Torataro Ushizukas; *The Elephant*, 2 volumes, by Etsujiro Sunamoto, from the author—the second copy presented by him; *Navaho Weaving: Its Technic and History*, by Charles Avery Amsden, from Frederick W. Hodge; *Cave Life of Kentucky*, by Vernon Bailey, from the author; *The Earth Upsets*, by Chase Salmon Osborn, from the author; *Indo-China: a Sportsman's Opportunity*, by Archibald Harrison, from Francis Burton Harrison; *Japan and America: a Journey and a Political Survey*, by Henry W. Taft, from the author; *Ruf, Haight, Eddy, Sumner, Hatch, and Allied Families*, from Mrs. Alpha H. Ruf; *The Benedicts Abroad*, by Clare Benedict, from the author; *Siam: Nature and Industry, and Siam: General and Medical Features*, from Hugh M. Smith; *The Development of the Peace Idea and Other Essays*, by Benjamin F. Trueblood, from Mrs. Benjamin F. Trueblood; *Le Livre d'Or de Victor Hugo . . . par des Ecrivains Contemporains*, from the Biblioteca Nacional, Buenos Aires. Among the gifts, too, were three important ethnological works from the library of her late brother, Daniel Folkmar, from Mrs. Etta F. Winter; a letter from R. R. Waldron to Sarah J. Hale on the U. S. Exploring Expedition (Wilkes). from Charles B. Hale; and several publications of a miscellaneous character, from Haydn T. Giles. Other gifts included 789 publications from the Library of Congress, 373 from the American Association for the Advancement of Science, 447 from the American Association of Museums, 563 from the Bureau of American Ethnology, 25 from the Anthropological Society of Washington, and several from the Geophysical Laboratory. Gifts were also received from Secretary

Abbot, Assistant Secretary Wetmore, Mrs. Charles D. Walcott, R. S. Bassler, E. A. Chapin, A. H. Clark, W. L. Corbin, W. F. Foshag, R. Kellogg, W. R. Maxon, G. S. Miller, Jr., G. S. Myers, A. J. Olmsted, M. J. Rathbun, H. Rehder, and F. M. Setzler.

SMITHSONIAN DEPOSIT

The Smithsonian deposit is the original and main library of the Institution. In 1866 this collection, then numbering 40,000, was transferred to the Library of Congress, where it has been increased to about 530,000 by regular sendings from the Smithsonian. Although on many subjects, the collection is concerned chiefly with the natural sciences and technology. It is especially complete in its files of the reports, proceedings, and transactions of learned societies and institutions, both American and foreign, and of scientific and technical journals and monographs.

During the past year the additions to the deposit from the Institution totaled 2,851 volumes, 9,596 parts of volumes, 5,185 pamphlets, and 15 charts. They included 5,973 dissertations. Many documents of foreign governments, addressed to the Institution but intended for the documents division of the Library of Congress, continued to come, especially by mail, to the Smithsonian library. They were forwarded promptly. The number of publications sent to the deposit in response to special requests was 2,255. Most of these were obtained on the basis of exchanges already established; many more than usual were found in the west stacks of the Institution as the result of the progress made during the year by the library staff, assisted by several competent C. W. A. employees, in organizing the collection of duplicates.

NATIONAL MUSEUM LIBRARY

The library of the United States National Museum was increased during the year by 14,842 publications, or 2,158 volumes, 11,699 parts of volumes, 965 pamphlets, and 20 charts. The library now numbers 86,738 volumes and 111,713 pamphlets. Among the accessions 1,593 were found in the Smithsonian duplicate collection, or received in response to special-request letters; 505 were obtained by transfer from the Library of Congress, and 77 by exchange from the Public Library of the District of Columbia. Many of the others were given by members of the scientific staff. The library prepared several hundred volumes for the bindery but, owing to lack of funds, was able to send only 128. The staff entered 11,731 periodicals, cataloged 3,111 publications, added 25,925 cards to the catalogs and shelf lists, filed 6,160 cards of the Concilium Bibliographicum, sorted and assigned to the sectional libraries thousands of others of this series, filed 463 cards of the Wistar Institute, and made 9,972 loans to the curators and their assistants and 110 to other libraries. They also sent 5,310

publications to the sectional libraries of the Museum. They borrowed 2,553 from the Library of Congress and 570 elsewhere, and returned 2,600 to the Library of Congress and 592 to other libraries. They advanced materially the reorganization of the technological library, where important changes in physical equipment occurred during the year. They also rendered the usual reference and informational service to scientists both inside and outside the Institution and to the general public.

The sectional libraries were unchanged. With the aid of a number of C. W. A. employees, the staff made considerable progress in cataloging their collections. These 35 libraries are as follows:

Administration	Invertebrate paleontology
Administrative assistant's office	Mammals
Agricultural history	Marine invertebrates
Anthropology	Medicine
Archeology	Minerals
Biology	Mollusks
Birds	Organic chemistry
Botany	Paleobotany
Echinoderms	Photography
Editor's office	Physical anthropology
Engineering	Property clerk's office
Ethnology	Reptiles and batrachians
Fishes	Superintendent's office
Foods	Taxidermy
Geology	Textiles
Graphic Arts	Vertebrate paleontology
History	Wood technology
Insects	

OFFICE LIBRARY

The office library consists of works of general reference, the publications of the Smithsonian and its branches, as well as of certain other learned institutions and societies, and many books and periodicals of more or less popular interest, including the collection once known as the "employees' library". In it, too, is the newly organized rare-book collection. The accessions for the last fiscal year were 173 volumes, 732 parts of volumes, and 19 pamphlets. The number of volumes bound was 100. The staff made 2,562 periodical entries, prepared 828 cards for the union catalog and 355 for the catalog of the technological library, filed 1,505 cards, mounted 847 aeronautical clippings in continuation of one of the projects begun under the C. W. A., answered 181 reference questions, loaned 2,765 publications, and received 2,439 visitors.

BUREAU OF AMERICAN ETHNOLOGY LIBRARY

The library of the Bureau of American Ethnology has to do mainly with the history, life, and culture of the early peoples of the Americas, especially the Indians of North America. Besides the 30,701 volumes

and 17,095 pamphlets in the collection, there are several Indian vocabularies and many manuscripts and photographs. The accessions in 1934 were 310 volumes and 102 pamphlets, most of which were obtained in exchange for the publications of the Bureau. The number of cards added to the catalog was 3,840, and of periodicals entered 3,130. The loans were 980.

ASTROPHYSICAL OBSERVATORY LIBRARY

The library of the Astrophysical Observatory contains 4,567 volumes and 3,828 pamphlets, chiefly on astrophysics and meteorology. It was increased in 1934 by 80 volumes, 102 pamphlets, and 14 charts. The number of periodicals entered was 1,216, of cards added to the catalog 647, and of volumes bound 60. The loans numbered 254.

RADIATION AND ORGANISMS LIBRARY

The additions to the library of the Division of Radiation and Organisms were 7 volumes, 236 parts of volumes, and 2 pamphlets. The collection now numbers 201 volumes, 12 pamphlets, and 6 charts.

LANGLEY AERONAUTICAL LIBRARY

The Langley aeronautical library, which since 1930 has been, for the most part, deposited, under its own name and bookplate, in the aeronautical division of the Library of Congress, received additions, as usual, during 1934 from the Smithsonian Institution. These totaled 581 publications—or 24 volumes, 521 parts of volumes, 12 pamphlets, and 24 charts—which increased the library to 1,978 volumes, 1,128 pamphlets, and 29 charts. Most of the rare items in the collection once belonged to Samuel Pierpont Langley, or to one of his well-known collaborators in aeronautics, especially Alexander Graham Bell, Octave Chanute, and James Means. In the library are sets of the early aeronautical periodicals and many valuable photographs and letters. There is also a mass of newspaper clippings. Classification of the clippings was begun during the year as one of the C. W. A. projects. It is being continued by a member of the Smithsonian library staff.

NATIONAL GALLERY OF ART LIBRARY

During the year the library of the National Gallery of Art was given more attention than usual by the regular staff, which was assisted for a few weeks by one of the C. W. A. workers. At the close of the year the collection numbered 2,131 volumes and 1,724 pamphlets, having been increased by 453 volumes and 215 pamphlets. Many of the additions were purchased; while 284 were received by transfer from the Library of Congress, and 16 from the library of the National Museum. The checking of the serial sets was continued, and missing

numbers were reported to the correspondence division of the Smithsonian library, with the result that 131 were obtained in exchange. The staff entered 1,247 periodicals. They catalogued 1,003 publications, classified 459, and added 7,675 cards to the catalog and shelf list, 3,725 of which they withdrew from the Museum files, where, for lack of adequate help, they had been obliged to leave them—many at least—since the days when the Gallery was a section of the National Museum and its library one of the Museum's sectional collections. This work of reorganization has increased materially the usefulness of the library as a reference tool in the activities of the Gallery. It will be continued as trained assistants can be spared from their duties elsewhere. The need of a full-time junior librarian in charge of the collection has become fully apparent, and it is hoped that one can soon be provided.

FREER GALLERY OF ART LIBRARY

The library of the Freer Gallery of Art has to do largely with the culture and art of the Far East, India, Persia, and the nearer East. Among its items are a number of important publications in Chinese and Japanese, which supplement to a degree those in the oriental division of the Library of Congress; also various books on American painters—especially James McNeill Whistler, many of whose works are in the Gallery—and on the famous fourth- and fifth-century manuscripts of the Bible, known as the "Washington Manuscripts", which are owned by the Freer. The main collection has 4,971 volumes and 3,465 pamphlets. The accessions for the year were 114 volumes and 66 pamphlets. The field collection remained essentially unchanged, at about 800 volumes and 500 pamphlets. In their effort to complete the cataloging of the library, the staff made noteworthy progress. They catalogued 670 volumes and 87 pamphlets, added 2,985 cards to the catalog and shelf list, and prepared 646 cards for the union catalog at the Smithsonian Institution. They also entered 145 periodicals, sent 22 volumes to the bindery, and rendered the usual reference service.

NATIONAL ZOOLOGICAL PARK LIBRARY

The library of the National Zoological Park received special consideration during the year. The entire collection was sorted, many items not needed by the Park were transferred to the Smithsonian Institution, and the rest were cataloged, entered, and arranged in appropriate rooms of the administration building. In this connection the staff, which consisted chiefly of C. W. A. workers, cataloged 2,088 volumes and pamphlets, filed 1,102 pamphlets roughly according to subject, recorded 1,168 periodicals, added 2,505 cards to the library catalog and shelf list, and prepared 1,718 others for the

union catalog at the Smithsonian. The library numbers 1,330 volumes and 1,860 pamphlets. The additions were 108 volumes and 1,450 pamphlets. Among these were 308 publications of the Smithsonian Institution and National Museum and 21 parts of the Proceedings of the Zoological Society of London that were missing from the sets at the Park. These were obtained from the Smithsonian library.

SUMMARY OF ACCESSIONS

The accessions for the year, which showed an increase of 3,527 over 1933, may be summarized as follows:

Library	Volumes	Pamphlets and charts	Total
Astrophysical Observatory.....	80	116	196
Bureau of American Ethnology.....	310	102	412
Freer Gallery of Art.....	114	66	180
Langley Aeronautical.....	24	36	60
National Gallery of Art.....	453	215	668
National Zoological Park.....	108	1,450	1,558
Radiation and Organisms.....	7	2	9
Smithsonian deposit, Library of Congress.....	2,851	5,200	8,051
Smithsonian office.....	173	19	192
United States National Museum.....	2,158	985	3,143
Total.....	6,278	8,191	14,469

At the close of the fiscal year the approximate number of items in the Smithsonian library system, not including the many thousands of volumes still uncataloged, unbound, and uncompleted, was as follows:

Volumes.....	597,461
Pamphlets.....	209,586
Charts.....	26,699
Total.....	833,746

If the exempt items referred to above were included in the count, together with the collections of reprints in the sectional libraries, the total would, of course, be much larger.

C. W. A. AND OTHER SPECIAL ACTIVITIES

The distinguishing event of the year was the appointment for a few weeks of 34 C. W. A. workers to assist the library staff. These employees, trained and experienced for the most part, made notable progress on the projects assigned to them, which were as follows: (1) Arranging the duplicate and other unorganized scientific and technical publications, many in foreign languages, with a view to getting them ready for the use of the library either in completing its sets or in obtaining by exchange much needed publications from other libraries; (2) preserving, putting in order, and making more quickly available thousands of cataloged volumes and pamphlets on the shelves, by

(a) labeling those without adequate location marks, (b) putting unbound pamphlets into binders and lettering them appropriately, and (c) making minor repairs, such as mending torn pages and tipping in loose plates; (3) classifying and indexing a large collection of valuable aeronautical material; (4) cataloging several special collections of scientific pamphlets; (5) preparing a dictionary catalog of the publications of the Smithsonian Institution and its affiliated bureaus; (6) making an index of the exchange relations of the library with other libraries, both American and foreign; and (7) preparing a union dictionary catalog of the publications in the various libraries of the Institution.

Since the withdrawal of the C. W. A. employees, further progress has been made on several of these projects by the regular staff, and one has even been completed to date—namely, the catalog of Smithsonian publications. The completing of the rest of the projects, however, will probably require many years.

Several other important pieces of work were undertaken by the staff. About 34,000 scientific reprints and pamphlets—many of much value—were selected from the material in the west stacks of the Smithsonian Building and distributed to the curators concerned; the Schoolcraft and Watkins collections were removed from the first floor of the main building to the second and third floors, thus making room for the growth of the botanical library; the organization of the American duplicates and of a large part of the foreign was finished, with the result that hundreds of important volumes and parts were found that were lacking in the standard sets, especially of the Smithsonian deposit and the library of the National Museum; nearly 17,000 duplicate and other unwanted publications, mainly in the technological library, were sorted out and transferred to various Government libraries where they would be of use, particularly the Library of Congress and the libraries of the Department of Agriculture, Geological Survey, Bureau of Mines, Office of Education, and Naval Research Laboratory; many hundred Government documents not needed by the library were returned to the Superintendent of Documents; about 1,800 dissertations, on medical and allied subjects, were sent to the library of the Surgeon General; special exchange credit on new publications essential to the work of the Institution was further built up by sending of duplicates to Harvard, Yale, Princeton, the University of Pennsylvania, and the Marine Biological Laboratory at Woods Hole, and a number of valuable items received in partial return; to meet a need that has become increasingly apparent in recent years in connection with the detailed study of the collections, a rare book section was set aside in the main hall of the Smithsonian Building where, under lock and key, especially rare and valuable publications can in the future be shelved; marked progress was made toward completing

the library's eight sets of the publications of the Institution and its bureaus, notably in consequence of the sorting and returning to stock of a large accumulation of these publications that had been sent back, as not needed, by college and other libraries throughout the country; the three files of Library of Congress analytical cards for the publications of the Institution and its bureaus were practically completed to date; the librarian sketched a book plate for the libraries of the Institution—which was turned into a finished design by the artist of the Bureau of American Ethnology—showing the unity of the Smithsonian library system, as well as the wide variety of the libraries that comprise it; finally, the union catalog was advanced as follows:

Volumes cataloged.....	8, 957
Pamphlets cataloged.....	3, 070
Charts cataloged.....	73
Typed cards added to catalog and shelf list.....	7, 229
Library of Congress cards added to catalog and shelf list.....	36, 357

Respectfully submitted.

WILLIAM L. CORBIN, *Librarian.*

Dr. C. G. ABBOT,

Secretary, Smithsonian Institution.

APPENDIX 10

REPORT ON PUBLICATIONS

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and the Government branches under its administrative charge during the year ending June 30, 1934.

The Institution published during the year 31 papers in the series of Smithsonian Miscellaneous Collections, 1 annual report and pamphlet copies of the 22 articles contained in the report appendix, and 3 special publications. The United States National Museum issued 1 annual report (published as part 2 of the Report of the Secretary of the Smithsonian Institution and as a separate therefrom), 2 complete bulletins, 1 part of a bulletin and 8 separates from the proceedings. The Bureau of American Ethnology issued 2 annual reports.

Of these publications, there were distributed 136,091 copies, which included 104 volumes and separates of the Smithsonian Contributions to Knowledge, 59,905 volumes and separates of the Smithsonian Miscellaneous Collections, 21,306 volumes and separates of the Smithsonian Annual Reports, 3,908 Smithsonian special publications, 35,127 volumes and separates of the National Museum publications, 14,761 publications of the Bureau of American Ethnology, 103 publications of the National Gallery of Art, 14 publications of the Freer Gallery of Art, 40 Annals of the Astrophysical Observatory, 18 reports of the Harriman Alaska Expedition, and 805 reports of the American Historical Association.

SMITHSONIAN MISCELLANEOUS COLLECTIONS

Of the Smithsonian Miscellaneous Collections, volume 85, there was issued the title page and table of contents; volume 86, title page and table of contents; volume 87, 3 papers and title page and table of contents; volume 88, whole volume and title page and table of contents; volume 89, 10 papers; volume 90, whole volume and title page and table of contents; volume 91, 15 papers; and volume 92, 1 paper, making 31 papers in all, as follows:

VOLUME 85

Title page and table of contents. (Publ. 3175.)

VOLUME 86

Title page and table of contents. (Publ. 3215.)

VOLUME 87

No. 18. Sun spots and weather, by C. G. Abbot. 10 pp., 5 text figs. (Publ. 3226.) November 20, 1933.

No. 19. An Oligocene eagle from Wyoming, by Alexander Wetmore. 9 pp., 19 text figs. (Publ. 3227.) December 26, 1933.

No. 20. Pliocene bird remains from Idaho, by Alexander Wetmore. 12 pp., 8 text figs. (Publ. 3228.) December 27, 1933.

Title page and table of contents. (Publ. 3239.)

VOLUME 88

(Whole volume.) Smithsonian Physical Tables, eighth revised edition, prepared by Frederick E. Fowle. 682 pp., 27 text figs. (Publ. 3171.) September 22, 1933.

Title page and table of contents. (Publ. 3240.)

VOLUME 89

No. 6. The classification of the free-living nematodes and their relation to the parasitic nematodes, by I. N. Filipjev. 63 pp., 8 pls. (Publ. 3216.) March 20, 1934. (Errata sheet issued June 13, 1934.)

No. 7. Evidence of Indian occupancy in Albemarle County, Virginia, by David I. Bushnell, Jr. 24 pp., 11 pls., 6 text figs. (Publ. 3217.) October 6, 1933.

No. 8. Morphology of the insect abdomen. Part II. The genital ducts and the ovipositor, by R. E. Snodgrass. 148 pp., 48 text figs. (Publ. 3219.) October 20, 1933.

No. 9. New Arctic foraminifera collected by Capt. R. A. Bartlett from Fox Basin and off the northeast coast of Greenland, by Joseph A. Cushman. 8 pp., 2 pls. (Publ. 3221.) September 30, 1933.

No. 10. Studies of American species of foraminifera of the genus *Lepidocyclina*, by Thomas Wayland Vaughan. 53 pp., 32 pls. (Publ. 3222.) December 4, 1933.

No. 11. Tertiary larger foraminifera of Venezuela, by Donald Winchester Gravell. 44 pp., 6 pls. (Publ. 3223.) December 9, 1933.

No. 12. Tribal migrations east of the Mississippi, by David I. Bushnell, Jr. 9 pp., 4 maps. (Publ. 3217.) March 20, 1934.

No. 13. A systematic classification for the birds of the world, revised and amended, by Alexander Wetmore. 11 pp. (Publ. 3242.) April 23, 1934.

No. 14. Millipeds of the West Indies and Guiana collected by the Allison V. Armour Expedition in 1932, by H. F. Loomis. 69 pp., 4 pls., 33 text figs. (Publ. 3244.) May 16, 1934.

No. 15. World weather and solar activity, by H. Helm Clayton. 52 pp., 26 text figs. (Publ. 3245.) May 31, 1934.

VOLUME 90

(Whole volume.) World weather records. Continued from volume 79. 1921-1930. Collected from official sources by Dr. G. C. Simpson, Robert C. Mossman, Sir Gilbert Walker, and Frances L. Clayton. Assembled and arranged for publication by H. Helm Clayton. Published under grant from John A. Roebling. 616 pp. (Publ. 3218.) May 18, 1934.

Title page and table of contents. (Publ. 3247.)

VOLUME 91

Reports on the collections obtained by the first Johnson-Smithsonian Deep-Sea Expedition to the Puerto Rican Deep.

No. 1. Station records of the first Johnson-Smithsonian Deep-Sea Expedition, by Paul Bartsch. 31 pp., 1 pl., 1 chart. (Publ. 3224.) December 1, 1933.

No. 2. New mollusks of the family Turritidae, by Paul Bartsch. 29 pp., 8 pls. (Publ. 3229.) May 29, 1934.

No. 3. A new crab of the genus *Cyclodorippe*, by Mary J. Rathbun. 1 p., 1 pl. (Publ. 3230.) February 5, 1934.

No. 4. Two new crinoids, by Austin H. Clark. 5 pp., 2 pls. (Publ. 3231.) February 7, 1934.

No. 5. A new nematode of the genus *Diplotriaeana* from a Hispaniolan woodpecker, by Everett E. Wehr. 3 pp., 1 text fig. (Publ. 3232.) February 2, 1934.

No. 6. New trematode parasites of birds, by Emmett W. Price. 6 pp., 1 pl. (Publ. 3233.) February 9, 1934.

No. 7. New digenetic trematodes from marine fishes, by Emmett W. Price. 8 pp., 1 pl. (Publ. 3234.) February 10, 1934.

No. 8. New polychaetous annelids, by Aaron L. Treadwell. 9 pp., 2 pls. (Publ. 3236.) March 23, 1934.

No. 9. Three new deep-water fishes from the West Indies, by George S. Myers. 12 pp., 1 pl. (Publ. 3238.) April 2, 1934.

No. 10. New brachiopods, by G. Arthur Cooper. 5 pp., 2 pls. (Publ. 3241.) April 12, 1934.

No. 11. Two new nematodes, by B. G. Chitwood. 4 pp., 1 pl. (Publ. 3243.) April 13, 1934.

No. 12. Three new amphipods, by Clarence R. Shoemaker. 6 pp., 3 text figs. (Publ. 3246.) June 1, 1934.

No. 13. A new genus of brittlestars from Puerto Rico, by Austin H. Clark. 3 pp., 1 pl. (Publ. 3248.) May 21, 1934.

No. 14. A new starfish from Puerto Rico, by Austin H. Clark. 3 pp., 1 pl. (Publ. 3249.) May 23, 1934.

No. 15. Two new congrid eels and a new flatfish, by Earl D. Reid. 11 pp., 1 pl. (Publ. 3251.) June 9, 1934.

VOLUME 92

No. 4. A new original version of Boscana's historical account of the San Juan Capistrano Indians of southern California, by John P. Harrington. 62 pp., 2 pls. (Publ. 3255.) June 27, 1934.

SMITHSONIAN ANNUAL REPORTS

Report for 1932.—The complete volume of the Annual Report of the Board of Regents for 1932 was received from the Public Printer in September 1933.

Annual Report of the Board of Regents of the Smithsonian Institution showing operations, expenditures, and condition of the Institution for the year ending June 30, 1932. xiii+497 pp., 55 pls., 79 text figs. (Publ. 3185.)

The appendix contained the following papers:

Solar radiation, by C. G. Abbot.

Variable stars, by L. V. Robinson.

The master key of science: Revealing the universe through the spectroscope, by Henry Norris Russell.

The decline of determinism, by Sir Arthur Eddington.

The measurement of noise, by G. W. C. Kaye.

The age of the earth and the age of the ocean, by Adolph Knopf.

A contribution to the geological history of the North Atlantic region, by Albert Gilligan.

The meteorite craters at Henbury, central Australia, by Arthur Richard Alderman.

Some geographical results of the Byrd Antarctic expedition, by Laurence M. Gould.

Some phases of modern deep-sea oceanography, with a description of some of the equipment and methods of the newly formed Woods Hole Oceanographic Institution, by C. O'D. Iselin, II.

Safety devices in wings of birds, by Lieut. Commander R. R. Graham.

Through forest and jungle in Kashmir and other parts of north India, by Casey A. Wood.

A decade of bird banding in America: A review, by Frederick C. Lincoln.

Insect enemies of insects and their relation to agriculture, by Curtis Clausen.

Plant records of the rocks, by A. C. Seward.

Cultivating algae for scientific research, by Florence E. Meier.

The present status of light therapy: Scientific and practical aspects, by Edgar Mayer.

The rise of man and modern research, by James H. Breasted.

Mohenjo-Daro and the ancient civilization of the Indus Valley, by Dorothy Mackay.

Historical cycles, by O. G. S. Crawford.

The "great wall of Peru" and other aerial photographic studies by the Shippee-Johnson Peruvian expedition, by Robert Shippee.

Status of woman in Iroquois polity before 1784, by J. N. B. Hewitt.

Report for 1933.—The report of the Secretary, in which the report of United States National Museum appeared as part 2, and which included the financial report of the executive committee of the Board of Regents, was issued in December 1933, and will form part of the annual report of the Board of Regents to Congress.

Report of the Secretary of the Smithsonian Institution and financial report of the executive committee of the Board of Regents for the year ending June 30, 1933. 194 pp. (Publ. 3225.)

SPECIAL PUBLICATIONS

Explorations and Field-Work of the Smithsonian Institution in 1933. 59 pp., 69 figs. (Publ. 3235.) March 14, 1934.

Classified list of Smithsonian publications available for distribution, November 1, 1933. Compiled by Helen Munroe. 33 pp. (Publ. 3220.) October 28, 1933.

(Reprint) The Smithsonian Institution. Revised statutes of the United States, 1878. Title LXXIII, with amendments to March 12, 1894. August 7, 1934.

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum has continued during the year under the immediate direction of the editor, Paul H. Oehser. There were issued 1 annual report, 2 complete bulletins, a part of a bulletin, and 8 separates from the proceedings.

The issues of the bulletin were as follows:

Bulletin 161, part 2. The foraminifera of the tropical Pacific collections of the *Albatross*, 1899-1900: Lagenidae to Alveolinellidae, by Joseph Augustine Cushman.

Bulletin 165. The bryozoan fauna of the Vincentown limesand, by Ferdinand Canu and Ray S. Bassler.

From Volume 26 of the Contributions from the United States National Herbarium: Part 7, The Mexican and Central American species of *Viburnum*, by C. V. Morton.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the bureau has continued under the immediate direction of the editor, Stanley Searles. During the year two annual reports were issued, as follows:

Forty-eighth Annual Report. Accompanying paper: General index, annual reports of the Bureau of American Ethnology, vols. 1-48 (Bonnerjea). v+1221 pp.

Fiftieth Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution, 1932-1933. 7 pp.

REPORT OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the association to the Secretary of the Smithsonian Institution and are communicated by him to Congress, as provided by the act of incorporation of the association.

The annual report for 1930, volumes 2 and 4, were issued during the year. The annual report for 1932 was in press at the close of the fiscal year.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

The manuscript of the Thirty-sixth Annual Report of the National Society, Daughters of the American Revolution, was transmitted to Congress, in accordance with law, December 28, 1933.

ALLOTMENTS FOR PRINTING

The congressional allotments for the printing of the Smithsonian Report to Congress and the various publications of the Government bureaus under the administration of the Institution were virtually used up at the close of the year. The appropriation for the coming year ending June 30, 1935, totals \$25,500, allotted as follows:

Smithsonian Institution.....	\$12, 750
National Museum.....	4, 750
American Historical Association.....	8, 000

Respectfully submitted.

W. P. TRUE, *Editor*.

DR. C. G. ABBOT,
Secretary, Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITH- SONIAN INSTITUTION

FOR THE YEAR ENDED JUNE 30, 1934

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN ENDOWMENT FUND

The original bequest of James Smithson was £104,960, 8s. 6d.; \$508,318.46. Refunds of money expended in prosecution of the claim, freights, insurance, etc., together with payment into the fund of the sum of £5,015 which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of..... \$550, 000. 00

Since the original bequest the Institution has received gifts from various sources, chiefly in the years prior to 1893, the income from which may be used for the general work of the Institution. To these gifts has been added capital from savings on income, gain from sale of securities, etc., bringing the total endowment for general purposes to the amount of..... 1, 119, 829. 09

The Institution holds also a number of endowment gifts, the income of each being restricted to specific use. These are invested and stand on the books of the Institution as follows:

Arthur, James, fund, income for investigations and study of sun and lecture on the sun.....	\$45, 225. 25
Bacon, Virginia Purdy, fund, for a traveling scholarship to investigate fauna of countries other than the United States.....	56, 654. 99
Baird, Lucy H., fund, for creating a memorial to Secretary Baird..	9, 618. 00
Barstow, Frederic D., fund, for purchase of animals for the Zoological Park.....	860. 18
Canfield Collection fund, for increase and care of the Canfield collection of minerals.....	43, 253. 33
Casey, Thomas L., fund, for maintenance of the Casey collection and promotion of researches relating to Coleoptera.....	8, 739. 32
Chamberlain, Francis Lea, fund, for increase and promotion of Isaac Lea collection of gems and mollusks.....	31, 844. 43
Hodgkins fund, specific, for increase and diffusion of more exact knowledge in regard to nature and properties of atmospheric air..	100, 000. 00
Hughes, Bruce, fund, to found Hughes alcove.....	17, 132. 00
Myer, Catherine Walden, fund, for purchase of first-class works of art for the use of and benefit of the National Gallery of Art....	21, 435. 86
Pell, Cornelia Livingston, fund, for maintenance of Alfred Duane Pell collection.....	2, 730. 24
Poore, Lucy T. and George W., fund, for general use of the Institution when principal amounts to the sum of \$250,000.....	64, 817. 17

Reid, Addison T., fund, for founding chair in biology in memory of Asher Tunis.....	\$26,361.98
Roebbling fund, for care, improvement, and increase of Roebbling collection of minerals.....	136,470.38
Rollins, Miriam and William, fund, for investigations in physics and chemistry.....	58,580.44
Springer, Frank, fund, for care, etc., of Springer collection and library.....	14,883.04
Walcott, Charles D. and Mary Vaux, research fund, for development of geological and paleontological studies and publishing results thereof.....	11,557.55
Younger, Helen Walcott, fund, held in trust.....	50,112.50
Zerbee, Frances Brincklé, fund, for endowment of aquaria.....	860.63
Total endowment for specific purposes other than Freer endowment.....	701,137.29

The capital funds of the Institution, except the Freer funds, are invested as follows:

Fund	U. S. Treasury	Consolidated fund	Separate funds	Total
Arthur, James.....		\$45,225.25		\$45,225.25
Bacon, Virginia Purdy.....		56,654.99		56,654.99
Baird, Lucy H.....		9,618.00		9,618.00
Barstow, Frederic D.....		860.18		860.18
Canfield Collection.....		43,253.33		43,253.33
Casey, Thomas L.....		8,739.32		8,739.32
Chamberlain.....		31,844.43		31,844.43
Hodgkins (specific).....	\$100,000			100,000.00
Hughes, Bruce.....		17,132.00		17,132.00
Myer, Catherine W.....		21,435.86		21,435.86
Pell, Cornelia Livingston.....		2,730.24		2,730.24
Poore, Lucy T. and George W.....	26,670	38,147.17		64,817.17
Reid, Addison T.....	11,000	15,361.98		26,361.98
Roebbling Collection.....		136,470.38		136,470.38
Rollins, Miriam and William.....		58,580.44		58,580.44
Smithsonian Special.....			\$1,400.00	1,400.00
Smithsonian unrestricted funds:				
Avery.....	14,000	42,110.09		56,110.09
Endowment.....		170,779.10		170,779.10
Habel.....	500			500.00
Hackenberg.....		4,549.81		4,549.81
Hamilton.....	2,500	456.48		2,956.48
Henry.....		1,367.64		1,367.64
Hodgkins (general).....	116,000	33,913.94		149,913.94
Parent.....	727,640	1,380.47		729,020.47
Rhees.....	590	534.95		1,124.95
Sanford.....	1,100	1,006.61		2,106.61
Springer.....			14,883.04	14,883.04
Walcott, Charles D. and Mary Vaux.....		11,557.55		11,557.55
Younger, Helen Walcott.....			50,112.50	50,112.50
Zerbee, Frances Brincklé.....		860.63		860.63
Total.....	1,000,000	754,570.84	66,395.54	1,820,966.38

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for the construction of a building to house the collection, and finally, in his will, probated November 6, 1919, he provided stock and securities to the estimated value of \$1,958,591.42 as an endowment fund for the operation of the gallery. From the above date to the present time these funds have been increased by stock dividends, savings of income, etc., to a total of \$4,700,436.50. In view of the importance and special

nature of the gift and the requirements of the testator in respect to it, all Freer funds are kept separate from the other funds of the Institution, and the accounting in respect to them is stated separately.

The invested funds of the Freer bequest are classified as follows:

Court and grounds fund.....	\$526, 598. 50
Court and grounds maintenance fund.....	132, 408. 27
Curator fund.....	535, 872. 86
Residuary legacy.....	3, 505, 556. 87
Total.....	<u>4, 700, 436. 50</u>

SUMMARY

Invested endowment for general purposes.....	\$1, 119, 829. 09
Invested endowment for specific purposes other than Freer endowment.....	<u>701, 137. 29</u>
Total invested endowment other than Freer endowment..	1, 820, 966. 38
Freer invested endowment for specific purposes.....	<u>4, 700, 436. 50</u>
Total invested endowment for all purposes.....	6, 521, 402. 88

CLASSIFICATION OF INVESTMENTS

Deposited in the United States Treasury at 6 percent per annum as authorized in the U. S. Revised Statutes, sec. 5591.....	\$1, 000, 000. 00
Investments other than Freer endowment (cost or market value at date acquired):	
Bonds (21 different groups).....	\$319, 771. 57
Stocks (41 different groups).....	445, 793. 46
Real estate first-mortgage notes.....	16, 550. 00
Uninvested capital.....	<u>38, 851. 35</u>
	820, 966. 38
Total investments other than Freer endowment.....	1, 820, 966. 38
Investments of Freer endowment (cost or market value at date acquired):	
Bonds (46 different groups).....	\$2, 189, 550. 61
Stocks (43 different groups).....	2, 409, 476. 30
Real estate first-mortgage notes.....	38, 500. 00
Uninvested capital.....	<u>62, 909. 59</u>
	4, 700, 436. 50
Total investments.....	6, 521, 402. 88

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING THE FISCAL YEAR ¹

Cash balance on hand June 30, 1933.....	\$183, 408. 25
Receipts:	
Cash income from various sources for general work of the Institution.....	\$72, 367. 48
Cash gifts expendable for special scientific objects (not to be invested).....	19, 215. 64
Cash income from endowments for specific use other than Freer endowment and from miscellaneous sources (including refund of temporary advances).....	<u>50, 821. 08</u>

¹ This statement does not include Government appropriations under the administrative charge of the Institution.

CASH BALANCES, RECEIPTS AND DISBURSEMENTS DURING THE FISCAL
YEAR—continued

Receipts—Continued.

Cash capital from sale, call of securities, etc.

(to be reinvested)----- \$133, 066. 73

Total receipts other than Freer endowment----- \$275, 470. 93

Cash receipts from Freer endowment:

Income from investments, etc----- \$200, 355. 55

Cash capital from sale, call of securities,

etc. (to be reinvested)----- 553, 646. 82

Total receipts from Freer endowment----- 754, 002. 37

Total----- 1, 212, 881. 55

Disbursements:

From funds for general work of the Institution:

Buildings, care, repairs, and alterations--- \$2, 138. 63

Furniture and fixtures----- 17. 47

General administration ²----- 21, 655. 51

Library----- 2, 500. 85

Publications (comprising preparation, print-
ing, and distribution)----- 18, 035. 98

Researches and explorations----- 23, 001. 50

Special fund----- 1, 400. 00

International exchanges----- 4, 415. 57

73, 165. 51

From funds for specific use, other than Freer
endowment:Investments made from gifts, from gain
from sale, etc., of securities and from
savings on income-----

9, 089. 11

Other expenditures, consisting largely of
research work, travel, increase and care
of special collections, etc., from income
of endowment funds and from cash gifts
for specific use (including temporary
advances)-----

68, 711. 57

Reinvestment of cash capital from sale,
call of securities, etc-----

104, 596. 82

182, 397. 50

From Freer endowment:

Operating expenses of the gallery, salaries,
field expenses, etc-----

51, 890. 62

Purchases of art objects----- 132, 736. 89

Investments made from gain from sale, etc.
of securities and from income-----

26, 131. 61

Reinvestment of cash capital from sale, call
of securities, etc-----

496, 440. 62

707, 199. 74

Cash balance June 30, 1934-----

250, 118. 80

Total----- 1, 212, 881. 55

² This includes salaries of the Secretary and certain others.

EXPENDITURES FOR RESEARCHES IN PURE SCIENCE, EXPLORATIONS, CARE, INCREASE, AND STUDY OF COLLECTIONS, ETC.

Expenditures from general funds of the Institution:

Publications.....	\$18, 035. 98	
Researches and explorations.....	23, 001. 50	
		\$41, 037. 48

Expenditures from funds devoted to specific purposes:

Researches and explorations.....	39, 737. 54	
Care, increase, and study of special collections.....	15, 057. 46	
Publications.....	2, 023. 93	
		56, 818. 93

Total.....		97, 856. 41
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The practice of depositing on time in local trust companies and banks such revenues as may be spared temporarily has been continued during the past year, and interest on these deposits has amounted to \$1,106.47.

The Institution gratefully acknowledges gifts or bequests from the following:

Dr. W. L. Abbott, purchase of collections of certain birds of the Himalayas.

Dr. Adolph M. Hanson, further income from certain royalties for conducting scientific work of the Institution.

Dr. T. Wayland Vaughan, publication of papers on Foraminifera.

Mr. Eldridge R. Johnson, for expenses in connection with deep-sea and other oceanographic explorations.

Mrs. Mary Vaux Walcott, for publication of pitcher-plant volume of North American Wild Flowers.

Research Corporation, further contributions for researches in radiation.

Dr. William Schaus, collection of Lepidoptera.

Mr. John A. Roebling, further contributions for researches in radiation.

All payments are made by check, signed by the Secretary of the Institution, on the Treasurer of the United States, and all revenues are deposited to the credit of the same account. In many instances deposits are placed in bank for convenience of collection and later are withdrawn in round amounts and deposited in the Treasury.

The foregoing report relates only to the private funds of the Institution.

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1934.

Salaries and expenses.....	\$32, 500	
International Exchanges.....	38, 500	
American Ethnology.....	50, 000	
Astrophysical Observatory.....	26, 500	
National Museum:		
Maintenance and operation.....	\$128, 500	
Preservation of collections.....	509, 000	
		637, 500

National Gallery of Art.....	\$29, 500
National Zoological Park.....	180, 000
Printing and binding.....	5, 500
Total.....	1, 000, 000

There was also an allotment of \$3,000 made by the United States Commission of the Chicago World's Fair Centennial Celebration for participation by the Smithsonian Institution in "A Century of Progress", and a grant of \$7,625 from the Federal Civil Works Administration to cover necessary overhead expenses in connection with the project "Archaeological Excavations."

The report of the audit of the Smithsonian private funds is printed below:

SEPTEMBER 25, 1934.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution, Washington, D. C.

SIRS: Pursuant to agreement we have audited the accounts of the Smithsonian Institution for the fiscal year ended June 30, 1934, and certify the balance of cash on hand June 30, 1934, to be \$252,018.80 [which includes \$1,900 held in cash at the Institution].

We have verified the record of receipts and disbursements maintained by the Institution and the agreement of the book balances with the bank balances.

We have examined all the securities in the custody of the Institution and in the custody of the banks and found them to agree with the book records.

We have compared the stated income of such securities with the receipts of record and found them in agreement therewith.

We have examined all vouchers covering disbursements for account of the Institution during the fiscal year ended June 30, 1934, together with the authority therefor, and have compared them with the Institution's record of expenditures and found them to agree.

We have examined and verified the accounts of the Institution with each trust fund.

We found the books of account and records well and accurately kept and the securities conveniently filed and securely cared for.

All information requested by your auditors was promptly and courteously furnished.

We certify the balance sheet, in our opinion, correctly presents the financial condition of the Institution as at June 30, 1934.

Respectfully submitted.

WILLIAM L. YAEGER & Co.,
WILLIAM L. YAEGER,
Certified Public Accountant.

Respectfully submitted.

FREDERIC A. DELANO,
R. WALTON MOORE,
JOHN C. MERRIAM,
Executive Committee.

GENERAL APPENDIX
TO THE
SMITHSONIAN REPORT FOR 1934

ADVERTISEMENT

The object of the **GENERAL APPENDIX** to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1934.

THE NEW WORLD-PICTURE OF MODERN PHYSICS¹

By SIR JAMES H. JEANS

The British Association assembles for the third time in Aberdeen—under the happiest of auspices. It is good that we are meeting in Scotland, for the Association has a tradition that its Scottish meetings are wholly successful. It is good that we are meeting in the sympathetic atmosphere of a university city, surrounded not only by beautiful and venerable buildings, but also by buildings in which scientific knowledge is being industriously and successfully accumulated. And it is especially good that Aberdeen is rich not only in scientific buildings but also in scientific associations. Most of us can think of some master mind in his own subject who worked here. My own thoughts, I need hardly say, turn to James Clerk Maxwell.

Whatever our subject, there is one man who will be in our thoughts in a very special sense tonight—Sir William Hardy, whom we had hoped to see in the presidential chair this year. It was not to be, and his early death, while still in the fullness of his powers, casts a shadow in the minds of all of us. We all know of his distinguished work in pure science, and his equally valuable achievements in applied science. I will not try to pay tribute to these, since it has been arranged that others, better qualified than myself, shall do so in a special memorial lecture. Perhaps, however, I may be permitted to bear testimony to the personal qualities of one whom I was proud to call a friend for a large part of my life, and a colleague for many years. Inside the council room his proposals were always acute, often highly original, and invariably worthy of careful consideration; outside, his big personality and wide range of interests made him the most charming and versatile of friends.

And now I must turn to the subject on which I have specially undertaken to speak—the new world-picture presented to us by modern physics. It is a full half century since this chair was last occupied by a theoretical physicist in the person of the late Lord Rayleigh. In that interval the main edifice of science has grown

¹ Presidential address before the British Association for the Advancement of Science, Aberdeen, 1934. Reprinted by permission from *Nature*, Sept. 8, 1934.

almost beyond recognition, increasing in extent, dignity, and beauty, as whole armies of laborers have patiently added wing after wing, story upon story, and pinnacle to pinnacle. Yet the theoretical physicist must admit that his own department looks like nothing so much as a building which has been brought down in ruins by a succession of earthquake shocks.

The earthquake shocks were, of course, new facts of observation, and the building fell because it was not built on the solid rock of ascertained fact, but on the ever-shifting sands of conjecture and speculation. Indeed it was little more than a museum of models, which had accumulated because the old-fashioned physicist had a passion for trying to liken the ingredients of Nature to familiar objects such as billiard balls, jellies, and spinning tops. While he believed and proclaimed that Nature had existed and gone her way for countless eons before man came to spy on her, he assumed that the latest newcomer on the scene, the mind which could never get outside itself and its own sensations, would find things within its limited experience to explain what had existed from all eternity. It was expecting too much of Nature, as the ruin of our building has shown. She is not so accommodating as this to the limitations of the human mind; her truths can only be made comprehensible in the form of parables.

Yet no parable can remain true throughout its whole range to the facts it is trying to explain. Somewhere or other it must be too wide or too narrow, so that "the truth, the whole truth, and nothing but the truth" is not to be conveyed by parables. The fundamental mistake of the old-fashioned physicist was that he failed to distinguish between the half truths of parables and the literal truth.

Perhaps his mistake was pardonable, perhaps it was even natural. Modern psychologists make great use of what they describe as "word-association." They shoot a word at you, and ask you to reply immediately with the first idea it evokes in your uncontrolled mind. If the psychologist says "wave", the boy-scout will probably say "flag", while the sailor may say "sea", the musician "sound", the engineer "compression", and the mathematician "sine" or "cosine". Now the crux of the situation is that the number of people who will give this last response is very small. Our remote ancestors did not survive in the struggle for existence by pondering over sines and cosines, but by devising ways of killing other animals without being killed themselves. As a consequence, the brains we have inherited from them take more kindly to the concrete facts of everyday life than to abstract concepts; to particulars rather than to universals. Every child, when first it begins to learn algebra, asks in despair "But what are x , y , and z ?" and is satisfied when, and only when,

it has been told that they are numbers of apples or pears or bananas or something such. In the same way, the old-fashioned physicist could not rest content with x , y , and z , but was always trying to express them in terms of apples or pears or bananas. Yet a simple argument will show that he can never get beyond x , y , and z .

Physical science obtains its knowledge of the external world by a series of exact measurements, or, more precisely, by comparisons of measurements. Typical of its knowledge is the statement that the line $H\alpha$ in the hydrogen spectrum has a wave length of so many centimeters. This is meaningless until we know what a centimeter is. The moment we are told that it is a certain fraction of the earth's radius, or of the length of a bar of platinum, or a certain multiple of the wave length of a line in the cadmium spectrum, our knowledge becomes real, but at that same moment it also becomes purely numerical. Our minds can only be acquainted with things inside themselves—never with things outside. Thus we can never know the essential nature of anything, such as a centimeter or a wave length, which exists in that mysterious world outside ourselves to which our minds can never penetrate; but we can know the numerical ratio of two quantities of similar nature, no matter how incomprehensible they may both be individually.

For this reason, our knowledge of the external world must always consist of numbers, and our picture of the universe—the synthesis of our knowledge—must necessarily be mathematical in form. All the concrete details of the picture, the apples and pears and bananas, the ether and atoms and electrons, are mere clothing that we ourselves drape over our mathematical symbols—they do not belong to Nature, but to the parables by which we try to make Nature comprehensible. It was, I think, Kronecker who said that in arithmetic God made the integers and man made the rest; in the same spirit, we may add that in physics God made the mathematics and man made the rest.

The modern physicist does not use this language, but he accepts its implications, and divides the concepts of physics into observables and unobservables. In brief, the observables embody facts of observation, and so are purely numerical or mathematical in their content; the unobservables are the pictorial details of the parables.

The physicist wants to make his new edifice earthquake proof—immune to the shock of new observations—and so builds only on the solid rock, and with the solid bricks, of ascertained fact. Thus he builds only with observables, and his whole edifice is one of mathematics and mathematical formulae—all else is man-made decoration.

For instance, when the undulatory theory had made it clear that light was of the nature of waves, the scientists of the day elaborated this by saying that light consisted of waves in a rigid, homogeneous ether which filled all space. The whole content of ascertained fact in this description is the one word "wave" in its strictly mathematical sense; all the rest is pictorial detail, introduced to help out the inherited limitations of our minds.

Then scientists took the pictorial details of the parable literally, and so fell into error. For instance, light waves travel in space and time jointly, but by filling space and space alone with ether, the parable seemed to make a clear-cut distinction between space and time. It even suggested that they could be separated out in practice—by performing a Michelson-Morley experiment. Yet, as we all know, the experiment when performed only showed that such a separation is impossible; the space and time of the parable are found not to be true to the facts—they are revealed as mere stage scenery. Neither is found to exist in its own right, but only as a way of cutting up something more comprehensive—the space-time continuum.

Thus we find that space and time cannot be classified as realities of nature, and the generalized theory of relativity shows that the same is true of their product, the space-time continuum. This can be crumpled and twisted and warped as much as we please without becoming one whit less true to nature—which, of course, can only mean that it is not itself part of nature.

In this way space and time, and also their space-time product, fall into their places as mere mental frameworks of our own construction. They are, of course, very important frameworks, being nothing less than the frameworks along which our minds receive their whole knowledge of the outer world. This knowledge comes to our minds in the form of messages passed on from our senses; these in turn have received them as impacts or transfers of electromagnetic momentum or energy. Now Clerk Maxwell showed that electromagnetic activity of all kinds could be depicted perfectly as traveling in space and time—this was the essential content of his electromagnetic theory of light. Thus space and time are of preponderating importance to our minds as the media through which the messages from the outer world enter the "gateways of knowledge", our senses, and in terms of which they are classified. Just as the messages which enter a telephone exchange are classified by the wires along which they arrive, so the messages which strike our senses are classified by their arrival along the space-time framework.

Physical science, assuming that each message must have had a starting point, postulated the existence of "matter" to provide such

starting points. But the existence of this matter was a pure hypothesis; and matter is in actual fact as unobservable as the ether, Newtonian force, and other unobservables which have vanished from science. Early science not only assumed matter to exist, but further pictured it as existing in space and time. Again this assumption had no adequate justification; for there is clearly no reason why the whole material universe should be restricted to the narrow framework along which messages strike our senses. To illustrate by an analogy, the earthquake waves which damage our houses travel along the surface of the ground, but we have no right to assume that they originate in the surface of the ground; we know, on the contrary, that they originate deep down in the earth's interior.

The Newtonian mechanics, however, having endowed space and time with real objective existences, assumed that the whole universe existed within the limits of space and time. Even more characteristic of it was the doctrine of "mechanistic determinism", which could be evolved from it by strictly logical processes. This reduced the whole physical universe to a vast machine in which each cog, shaft, and thrust bar could only transmit what it received, and wait for what was to come next. When it was found that the human body consisted of nothing beyond commonplace atoms and molecules, the human race also seemed to be reduced to cogs in the wheel, and in the face of the inexorable movements of the machine, human effort, initiative, and ambition seemed to become meaningless illusions. Our minds were left with no more power or initiative than a sensitized cinematograph film; they could only register what was impressed on them from an outer world over which they had no control.

Theoretical physics is no longer concerned to study the Newtonian universe which it once believed to exist in its own right in space and time. It merely sets before itself the modest task of reducing to law and order the impressions that the universe makes on our senses. It is not concerned with what lies beyond the gateways of knowledge, but with what enters through the gateways of knowledge. It is concerned with appearances rather than reality, so that its task resembles that of the cartographer or mapmaker rather than that of the geologist or mining engineer.

Now the cartographer knows that a map may be drawn in many ways, or, as he would himself say, many kinds of projection are available. Each one has its merits, but it is impossible to find all the merits we might reasonably desire combined in one single map. It is reasonable to demand that each bit of territory should look its proper shape on the map; also that each should look its proper relative size. Yet even these very reasonable requirements cannot

usually be satisfied in a single map; the only exception is when the map is to contain only a small part of the whole surface of the globe. In this case, and this only, all the qualities we want can be combined in a single map, so that we simply ask for a map of the county of Surrey without specifying whether it is to be a Mercator's or orthographic or conic projection, or whatnot.

All this has its exact counterpart in the map-making task of the physicist. The Newtonian mechanics was like the map of Surrey, because it dealt only with a small fraction of the universe. It was concerned with the motions and changes of medium-sized objects—objects comparable in size with the human body—and for these it was able to provide a perfect map which combined in one picture all the qualities we could reasonably demand. But the inconceivably great and the inconceivably small were equally beyond its ken. As soon as science pushed out—to the cosmos as a whole in one direction and to subatomic phenomena in the other—the deficiencies of the Newtonian mechanics became manifest. And no modification of the Newtonian map was able to provide the two qualities which this map had itself encouraged us to expect—a materialism which exhibited the universe as constructed of matter lying within the framework of space and time, and a determinism which provided an answer to the question “What is going to happen next?”

When geography cannot combine all the qualities we want in a single map, it provides us with more than one map. Theoretical physics has done the same, providing us with two maps which are commonly known as the particle-picture and the wave-picture.

The particle-picture is a materialistic picture which caters for those who wish to see their universe mapped out as matter existing in space and time. The wave-picture is a determinist picture which caters for those who ask the question “What is going to happen next?” It is perhaps better to speak of these two pictures as the particle-parable and the wave-parable. For this is what they really are, and the nomenclature warns us in advance not to be surprised at inconsistencies and contradictions.

Let me remind you, as briefly as possible, how this pair of pictures or parables have come to be in existence side by side.

The particle parable, which was first in the field, told us that the material universe consists of particles existing in space and time. It was created by the labors of chemists and experimental physicists, working on the basis provided by the classical physics. Its time of testing came in 1913, when Bohr tried to find out whether the two particles of the hydrogen atom could possibly produce the highly complicated spectrum of hydrogen by their motion. He found a type of motion which could produce this spectrum down to its minutest details,

but the motion was quite inconsistent with the mechanistic determinism of the Newtonian mechanics. The electron did not move continuously through space and time, but jumped, and its jumps were not governed by the laws of mechanics, but to all appearance, as Einstein showed more fully 4 years later, by the laws of probability. Of 1,000 identical atoms, 100 might make the jump, while the other 900 would not. Before the jumps occurred, there was nothing to show which atoms were going to jump. Thus the particle picture conspicuously failed to provide an answer to the question, "What will happen next?"

Bohr's concepts were revolutionary, but it was soon found they were not revolutionary enough, for they failed to explain more complicated spectra, as well as certain other phenomena.

Then Heisenberg showed that the hydrogen spectrum—and, as we now believe, all other spectra as well—could be explained by the motion of something which was rather like an electron, but did not move in space and time. Its position was not specified by the usual coordinates x, y, z of coordinate geometry, but by the mathematical abstraction known as a "matrix." His ideas were rather too abstract even for mathematicians, the majority of whom had quite forgotten what matrices were. It seemed likely that Heisenberg had unravelled the secret of the structure of matter, and yet his solution was so far removed from the concepts of ordinary life that another parable had to be invented to make it comprehensible.

The wave parable serves this purpose; it does not describe the universe as a collection of particles but as a system of waves. The universe is no longer a deluge of shot from a battery of machine guns, but a stormy sea with the sea taken away and only the abstract quality of storminess left—or the grin of the Cheshire cat if we can think of a grin as undulatory. This parable was not devised by Heisenberg, but by de Broglie and Schrodinger. At first they thought their waves merely provided a superior model of an ordinary electron; later it was established that they were a sort of parable to explain Heisenberg's pseudoelectron.

Now the pseudoelectron of Heisenberg did not claim to account for the spectrum emitted by a single atom of gas, which is something entirely beyond our knowledge or experience, but only that emitted by a whole assembly of similar atoms; it was not a picture of one electron in one atom, but of all the electrons in all the atoms.

In the same way the waves of the wave parable do not picture individual electrons, but a community of electrons—a crowd—as for instance the electrons whose motion constitutes a current of electricity.

In this particular instance the waves can be represented as traveling through ordinary space. Except for traveling at a different speed,

they are very like the waves by which Maxwell described the flow of radiation through space, so that matter and radiation are much more like one another in the new physics than they were in the old.

In other cases, ordinary time and space do not provide an adequate canvas for the wave picture. The wave picture of two currents of electricity, or even of two electrons moving independently, needs a larger canvas—six dimensions of space and one of time. There can be no logical justification for identifying any particular three of these six dimensions with ordinary space, so that we must regard the wave picture as lying entirely outside space. The whole picture, and the manifold dimensions of space in which it is drawn, become pure mental constructs—diagrams and frameworks we make for ourselves to help us understand phenomena.

In this way we have the two coexistent pictures—the particle picture for the materialist, and the wave picture for the determinist. When the cartographer has to make two distinct maps to exhibit the geography of, say, North America, he is able to explain why two maps are necessary, and can also tell us the relation between the two—he can show us how to transform one into the other. He will tell us, for instance, that he needs two maps simply because he is restricted to flat surfaces—pieces of paper. Give him a sphere instead and he can show us North America, perfectly and completely, on a single map.

The physicist has not yet found anything corresponding to this sphere; when, if ever, he does, the particle picture and the wave picture will be merged into a single new picture. At present some kink in our minds, or perhaps merely some ingrained habit of thought, prevents our understanding the universe as a consistent whole—just as the ingrained habits of thought of a “flat-earthier” prevent his understanding North America as a consistent whole. Yet, although physics has so far failed to explain why two pictures are necessary, it is, nevertheless, able to explain the relation between the particle picture and the wave picture in perfectly comprehensible terms.

The central feature of the particle picture is the atomicity which is found in the structure of matter. But this atomicity is only one expression of a fundamental coarse-grainedness which pervades the whole of nature. It crops up again in the fact that energy can only be transferred by whole quanta. Because of this, the tools with which we study nature are themselves coarse-grained; we have only blunt probes at our disposal, and so can never acquire perfectly precise knowledge of nature. Just as, in astronomy, the grain of our photographic plates prevents our ever fixing the position of a star with absolute precision, so in physics we can never say that an electron is here, at this precise spot, and is moving at just such and such a speed. The best we can do with our blunt probes is to represent

the position of the electron by a smear, and its motion by a moving smear which will get more and more blurred as time progresses. Unless we check the growth of our smear by taking new observations, it will end by spreading through the whole of space.

Now the waves of an electron or other piece of matter are simply a picture of just such a smear. Where the waves are intense, the smear is black, and conversely. The nature of the smear—whether it consists of printer's ink, or, as was at one time thought, of electricity—is of no importance; this is mere pictorial detail. All that is essential is the relative blackness of the smear at different places—a ratio of numbers which measures the relative chance of electrons being at different points of space.

The relation between the wave picture and the particle picture may be summed up thus: The more stormy the waves at any point in the wave picture the more likely we are to find a particle at that point in the particle picture. Yet if the particles really existed as points and the waves depicted the chances of their existing at different points of space—as Maxwell's law does for the molecules of a gas—then the gas would emit a continuous spectrum instead of the line spectrum that is actually observed. Thus we had better put our statement in the form that the electron is not a point particle, but that if we insist on picturing it as such, then the waves indicate the relative proprieties of picturing it as existing at the different points of space. But propriety relative to what?

The answer is—relative to our own knowledge. If we know nothing about an electron except that it exists, all places are equally likely for it, so that its waves are uniformly spread through the whole of space. By experiment after experiment we can restrict the extent of its waves, but we can never reduce them to a point or, indeed, below a certain minimum; the coarse-grainedness of our probes prevents that. There is always a finite region of waves left. And the waves which are left depict our knowledge precisely and exactly; we may say that they are waves of knowledge—or, perhaps even better still, waves of imperfections of knowledge—of the position of the electron.

And now we come to the central and most surprising fact of the whole situation. I agree that it is still too early, and the situation is still too obscure, for us fully to assess its importance, but, as I see it, it seems likely to lead to radical changes in our views not only of the universe but even more of ourselves. Let us remember that we are dealing with a system of waves which depicts in a graphic form our knowledge of the constituents of the universe. The central fact is this: The wave parable does not tell us that these waves depict our knowledge of nature, but that they are nature itself.

If we ask the new physics to specify an electron for us, it does not give us a mathematical specification of an objective electron, but rather retorts with the question: "How much do you know about the electron in question?" We state all we know, and then comes the surprising reply, "That is the electron." The electron exists only in our minds—what exists beyond, and where, to put the idea of an electron into our minds we do not know. The new physics can provide us with wave-pictures depicting electrons about which we have varying amounts of knowledge, ranging from nothing at all to the maximum we can know with the blunt probes at our command, but the electron which exists apart from our study of it is quite beyond its purview.

Let me try and put this in another way. The old physics imagined it was studying an objective nature which had its own existence independently of the mind which perceived it—which, indeed, had existed from all eternity whether it was perceived or not. It would have gone on imagining this to this day, had the electron observed by the physicists behaved as on this supposition it ought to have done.

But it did not so behave, and this led to the birth of the new physics, with its general thesis that the nature we study does not consist so much of something we perceive as of our perceptions; it is not the object of the subject-object relation, but the relation itself. There is, in fact, no clear-cut division between the subject and object; they form an indivisible whole which now becomes nature. This thesis finds its final expression in the wave-parable, which tells us that nature consists of waves and that these are of the general quality of waves of knowledge, or of absence of knowledge, in our own minds.

Let me digress to remind you that if ever we are to know the true nature of waves, these waves must consist of something we already have in our own minds. Now knowledge and absence of knowledge satisfy this criterion as few other things could; waves in an ether, for instance, emphatically did not. It may seem strange, and almost too good to be true, that nature should in the last resort consist of something we can really understand; but there is always the simple solution available that the external world is essentially of the same nature as mental ideas.

At best this may seem very academic and up in the air—at the worst it may seem stupid and even obvious. I agree that it would be so, were it not for the one outstanding fact that observation supports the wave-picture of the new physics whole-heartedly and without hesitation. Whenever the particle-picture and the wave-picture have come into conflict, observation has discredited the

particle-picture and supported the wave-picture—not merely, be it noted, as a picture of our knowledge of nature, but as a picture of nature itself. The particle-parable is useful as a concession to the materialistic habits of thought which have become ingrained in our minds, but it can no longer claim to fit the facts, and, so far as we can at present see, the truth about nature must lie very near to the wave-parable.

Let me digress again to remind you of two simple instances of such conflicts and of the verdicts which observation has pronounced upon them.

A shower of parallel-moving electrons forms in effect an electric current. Let us shoot such a shower of electrons at a thin film of metal, as your own Prof. G. P. Thomson did. The particle-parable compares it to a shower of hailstones falling on a crowd of umbrellas; we expect the electrons to get through somehow or anyhow and come out on the other side as a disordered mob. But the wave-parable tells us that the shower of electrons is a train of waves. It must retain its wave-formation, not only in passing through the film, but also when it emerges on the other side. And this is what actually happens; it comes out and forms a wave-pattern which can be predicted—completely and perfectly—from its wave-picture before it entered the film.

Next let us shoot our shower of electrons against the barrier formed by an adverse electromotive force. If the electrons of the shower have a uniform energy of 10 volts each, let us throw them against an adverse potential difference of a million volts. According to the particle-parable, it is like throwing a handful of shot up into the air; they will all fall back to earth in time—the conservation of energy will see to that. But the wave-parable again sees our shower of electrons as a train of waves—like a beam of light—and sees the potential barrier as an obstructing layer—like a dirty window pane. The wave-parable tells us that this will check, but not entirely stop, our beam of electrons. It even shows us how to calculate what fraction will get through. And just this fraction, in actual fact, does get through; a certain number of 10-volt electrons surmount the potential barrier of a million volts—as though a few of the shot thrown lightly up from our hands were to surmount the earth's gravitational field and wander off into space. The phenomenon appears to be in flat contradiction to the law of conservation of energy, but we must remember that waves of knowledge are not likely to own allegiance to this law.

A further problem arises out of this experiment. Of the millions of electrons of the original shower, which particular electrons will get through the obstacle? Is it those who get off the mark

first, or those with the highest turn of speed, or what? What little extra have they that the others haven't got?

It seems to be nothing more than pure good luck. We know of no way of increasing the chances of individual electrons; each just takes its turn with the rest. It is a concept with which science has been familiar ever since Rutherford and Soddy gave us the law of spontaneous disintegration of radioactive substances—of a million atoms 10 broke up every year, and no help we could give to a selected 10 would cause fate to select them rather than the 10 of her own choosing. It was the same with Bohr's model of the atom; Einstein found that without the caprices of fate it was impossible to explain the ordinary spectrum of a hot body; call on fate, and we at once obtained Planck's formula, which agrees exactly with observation.

From the dawn of human history, man has been wont to attribute the results of his own incompetence to the interference of a malign fate. The particle-picture seems to make fate even more powerful and more all-pervading than ever before; she not only has her finger in human affairs, but also in every atom in the universe. The new physics has got rid of mechanistic determinism, but only at the price of getting rid of the uniformity of nature as well!

I do not suppose that any serious scientist feels that such a statement must be accepted as final; certainly I do not. I think the analogy of the beam of light falling on the dirty windowpane will show us the fallacy of it.

Heisenberg's mathematical equation shows that the energy of a beam of light must always be an integral number of quanta. We have observational evidence of this in the photoelectric effect, in which atoms always suffer damage by whole quanta.

Now this is often stated in parable form. The parable tells us that light consists of discrete light-particles, called photons, each carrying a single quantum of energy. A beam of light becomes a shower of photons moving through space like the bullets from a machinegun; it is easy to see why they necessarily do damage by whole quanta.

When a shower of photons falls on a dirty windowpane, some of the photons are captured by the dirt, while the rest escape capture and get through. And again the question arises: How are the lucky photons singled out? The obvious superficial answer is a wave of the hand toward Fortune's wheel; it is the same answer that Newton gave when he spoke of his "corpuscles of light" experiencing alternating fits of transmission and reflection. But we readily see that such an answer is superficial.

Our balance at the bank always consists of an integral number of pence, but it does not follow that it is a pile of bronze pennies. A child may, however, picture it as so being, and ask his father what determines which particular pennies go to pay the rent. The father may answer "Mere chance"—a foolish answer, but no more foolish than the question. Our question as to what determines which photons get through is, I think, of a similar kind, and if Nature seems to answer "Mere chance," she is merely answering us according to our folly. A parable which replaces radiation by identifiable photons can find nothing but the finger of fate to separate the sheep from the goats. But the finger of fate, like the photons themselves, is mere pictorial detail. As soon as we abandon our picture of radiation as a shower of photons, there is no chance but complete determinism in its flow. And the same is, I think, true when the particle-photons are replaced by particle-electrons.

We know that every electric current must transfer electricity by complete electron-units, but this does not entitle us to replace an electric current by a shower of identifiable electron-particles. Indeed the general principles of quantum-mechanics, which are in full agreement with observation, definitely forbids our doing so. When the red and white balls collide on a billiard table, red may go to the right and white to the left. The collision of two electrons A and B is governed by similar laws of energy and momentum, so that we might expect to be able to say that A goes to the right, and B to the left or vice versa. Actually we must say no such thing, because we have no right to identify the two electrons which emerge from the collision with the two that went in. Its as though A and B had temporarily combined into a single drop of electric fluid, which had subsequently broken up into two new electrons, C, D. We can only say that after the collision C will go to the right, and D to the left. If we are asked which way A will go, the true answer is that by then A will no longer exist. The superficial answer is that it is a pure toss-up. But the toss-up is not in nature, but in our own minds; it is an even chance whether we choose to identify C with A or with B.

Thus the indeterminism of the particle-picture seems to reside in our own minds rather than in nature. In any case this picture is imperfect, since it fails to represent the facts of observation. The wave-picture, which observation confirms in every known experiment, exhibits a complete determinism.

Again we may begin to feel that the new physics is little better than the old—that it has merely replaced one determinism by another. It has; but there is all the difference in the world between the two determinisms. For in the old physics the perceiving mind was a spectator; in the new it is an actor. Nature no longer forms

a closed system detached from the perceiving mind; the perceiver and perceived are interacting parts of a single system. The nature depicted by the wave-picture in some way embraces our minds as well as inanimate matter. Things still change solely as they are compelled, but it no longer seems impossible that part of the compulsion may originate in our own minds.

Even the inadequate particle-picture told us something very similar in its own roundabout stammering way. At first it seemed to be telling us of a nature distinct from our minds, which moved as directed by throws of the dice, and then it transpired that the dice were thrown by our own minds. Our minds enter into both pictures, although in somewhat different capacities. In the particle-picture the mind merely decides under what conventions the map is to be drawn; in the wave-picture it perceives and observes and draws the map. We should notice, however, that the mind enters both pictures only in its capacity as a receptacle—never as an emitter.

The determinism which appears in the new physics is one of waves, and so, in the last resort, of knowledge. Where we are not ourselves concerned, we can say that event follows event; where we are concerned, only that knowledge follows knowledge. And even this knowledge is one only of probabilities and not of certainties; it is at best a smeared picture of the clear-cut reality which we believe to lie beneath. And just because of this, it is impossible to decide whether the determinism of the wave-picture originates in the underlying reality or not—can our minds change what is happening in reality, or can they only make it look different to us by changing our angle of vision? We do not know, and as I do not see how we can ever find out, my own opinion is that the problem of free-will will continue to provide material for fruitless discussion until the end of eternity.

The contribution of the new physics to this problem is not that it has given a decision on a long-debated question, but that it has reopened a door which the old physics had seemed to slam and bolt. We have an intuitive belief that we can choose our lunch from the menu or abstain from housebreaking or murder; and that by our own volition we can develop our freedom to choose. We may, of course be wrong. The old physics seemed to tell us that we were, and that our imagined freedom was all an illusion; the new physics tells us it may not be.

The old physics showed us a universe which looked more like a prison than a dwelling place. The new physics shows a building which is certainly more spacious, although its interior doors may be either open or locked—we cannot say. But we begin to suspect it may give us room for such freedom as we have always believed we possessed; it seems possible at least that in it we can mold events

to our desire, and live lives of emotion, intellect, and endeavor. It looks as though it might form a suitable dwelling place for man, and not a mere shelter for brutes.

The new physics obviously carries many philosophical implications, but these are not easy to describe in words. They cannot be summed up in the crisp, snappy sentences beloved of scientific journalism, such as that materialism is dead, or that matter is no more. The situation is rather that both materialism and matter need to be redefined in the light of our new knowledge. When this has been done, the materialist must decide for himself whether the only kind of materialism which science now permits can be suitably labeled materialism, and whether what remains of matter should be labeled as matter or as something else; it is mainly a question of terminology.

What remains is in any case very different from the full-blooded matter and the forbidding materialism of the Victorian scientist. His objective and material universe is proved to consist of little more than constructs of our own minds. To this extent, then, modern physics has moved in the direction of philosophic idealism. Mind and matter, if not proved to be of similar nature, are at least found to be ingredients of one single system. There is no longer room for the kind of dualism which has haunted philosophy since the days of Descartes.

This brings us at once face to face with the fundamental difficulty which confronts every form of philosophical idealism. If the nature we study consists so largely of our own mental constructs, why do our many minds all construct one and the same nature? Why, in brief, do we all see the same sun, moon, and stars?

I would suggest that physics itself may provide a possible although very conjectural clue. The old particle-picture which lay within the limits of space and time, broke matter up into a crowd of distinct particles, and radiation into a shower of distinct photons. The newer and more accurate wave-picture, which transcends the framework of space and time, recombines the photons into a single beam of light, and the shower of parallel-moving electrons into a continuous electric current. Atomicity and division into individual existences are fundamental in the restricted space-time picture, but disappear in the wider, and as far as we know, more truthful, picture which transcends space and time. In this, atomicity is replaced by what General Smuts would describe as "holism"—the photons are no longer distinct individuals each going its own way, but members of a single organization or whole—a beam of light. The same is true, *mutatis mutandis*, of the electrons of a parallel-moving shower. The biologists are beginning to tell us, although not very unanimously,

that the same may be true of the cells of our bodies. And is it not conceivable that what is true of the objects perceived may be true also of the perceiving minds? When we view ourselves in space and time we are quite obviously distinct individuals; when we pass beyond space and time we may perhaps form ingredients of a continuous stream of life. It is only a step from this to a solution of the problem which would have commended itself to many philosophers, from Plato to Berkeley, and is, I think, directly in line with the new world-picture of modern physics.

I have left but little time to discuss affairs of a more concrete nature. We meet in a year which has to some extent seen science arraigned before the bar of public opinion; there are many who attribute most of our present national woes—including unemployment in industry and the danger of war—to the recent rapid advance in scientific knowledge.

Even if their most lurid suspicions were justified, it is not clear what we could do. For it is obvious that the country which called a halt to scientific progress would soon fall behind in every other respect as well—in its industry, in its economic position, in its naval and military defenses, and not least important, in its culture. Those who sigh for an Arcadia in which all machinery would be scrapped and all invention proclaimed a crime, as it was in Erewhon, forget that the Erewhonians had neither to compete with highly organized scientific competitors for the trade of the world nor to protect themselves against possible bomb-dropping, blockade, or invasion.

But can we admit that the suspicions of our critics are justified? If science has made the attack more deadly in war, it has also made the defense more efficient; in the long run it shows no partiality in the age-long race between weapons of attack and defense. This being so, it would, I think, be hard to maintain in cold blood that its activities are likely to make wars either more frequent or more prolonged. It is at least arguable that the more deadly a war is likely to be, the less likely it is to occur.

Still it may occur. We cannot ignore the tragic fact that, as our President of 2 years ago told us, science has given man control over Nature before he has gained control over himself. The tragedy does not lie in man's scientific control over Nature but in his absence of moral control over himself. This is only one chapter of a long story—human nature changes very slowly, and so forever lags behind human knowledge, which accumulates very rapidly. The plays of Aeschylus and Sophocles still thrill us with their vital human interest, but the scientific writings of Aristarchus and Ptolemy are dead—mere historical curiosities which leave us cold. Scientific knowledge is transmitted from one generation to another,

while acquired characteristics are not. Thus, in respect of knowledge, each generation stands on the shoulders of its predecessor, but in respect of human nature, both stand on the same ground.

These are hard facts which we cannot hope to alter, and which—we may as well admit—may wreck civilization. If there is an avenue of escape, it does not, as I see it, lie in the direction of less science, but of more science—psychology, which holds out hopes that, for the first time in his long history, man may be enabled to obey the command “Know thyself”; to which I for one, would like to see adjoined a morality and, if possible, even a religion, consistent with our new psychological knowledge and the established facts of science; scientific and constructive measures of eugenics and birth control; scientific research in agriculture and industry, sufficient at least to defeat the gloomy prophecies of Malthus and enable ever larger populations to live in comfort and contentment on the same limited area of land. In such ways we may hope to restrain the pressure of population and the urge for expansion which, to my mind, are far more likely to drive the people of a nation to war than the knowledge that they—and also the enemies they will have to fight—are armed with the deadliest weapons which science can devise.

This last brings us to the thorny problem of economic depression and unemployment. No doubt a large part of this results from the war, national rivalries, tariff barriers, and various causes which have nothing to do with science, but a residue must be traced to scientific research; this produces labor-saving devices which in times of depression are only too likely to be welcomed as wage-saving devices and to put men out of work. The scientific Robot in *Punch's* cartoon boasted that he could do the work of 100 men, but gave no answer to the question—“Who will find work for the displaced 99?” He might, I think, have answered—“The pure scientist in part, at least.” For scientific research has two products of industrial importance—the labor-saving inventions which displace labor, and the more fundamental discoveries which originate as pure science, but may ultimately lead to new trades and new popular demands providing employment for vast armies of labor.

Both are rich gifts from science to the community. The labor-saving devices lead to emancipation from soul-destroying toil and routine work to greater leisure and better opportunities for its enjoyment. The new inventions add to the comfort and pleasure, health and wealth of the community. If a perfect balance could be maintained between the two, there would be employment for all, with a continual increase in the comfort and dignity of life. But, as I see it, troubles are bound to arise if the balance is not maintained, and a steady flow of labor-saving devices with no accompanying

steady flow of new industries to absorb the labor they displace, cannot but lead to unemployment and chaos in the field of labor. At present we have a want of balance resulting in unemployment, so that our great need at the moment is for industry-making discoveries. Let us remember Faraday's electromagnetic induction, Maxwell's Hertzian waves, and the Otto cycle—each of which has provided employment for millions of men. And, although it is an old story, let us also remember that the economic value of the work of one scientist alone, Edison, has been estimated at three thousand million pounds.

Unhappily, no amount of planning can arrange a perfect balance. For as the wind bloweth where it listeth, so no one can control the direction in which science will advance; the investigator in pure science does not know himself whether his researches will result in a mere labor-saving device or a new industry. He only knows that if all science were throttled down, neither would result; the community would become crystallized in its present state, with nothing to do but watch its population increase, and shiver as it waited for the famine, pestilence, or war which must inevitably come to restore the balance between food and mouths, land and population.

Is it not better to press on in our efforts to secure more wealth and leisure and dignity of life for our own and future generations, even though we risk a glorious failure, rather than accept inglorious failure by perpetuating our present conditions, in which these advantages are the exception rather than the rule? Shall we not risk the fate of that over-ambitious scientist Icarus, rather than resign ourselves without an effort to the fate which has befallen the bees and ants? Such are the questions I would put to those who maintain that science is harmful to the race.

THE MARKINGS AND ROTATION OF MERCURY¹

By E. M. ANTONIADI

It is a well-known fact that the planet Mercury has been singularly neglected by astronomers, so that the greatest confusion is reigning as to the reality and configuration of its spots, the duration of its rotation period, or even the existence of its atmosphere. This uncertainty strikes its roots in the smallness of the disk of Mercury; in the practical hopelessness of detecting well-defined markings on his surface at the very low altitude, and consequent rippling air, of twilight and dawn; and in the difficulty of finding the planet itself without an equatorial mounting, at daytime, high above the horizon, and in the overpowering glare of the Sun.

In the beginning of the nineteenth century, Schröter drew mountains, a dark streak, and other spots on Mercury, from which Bessel deduced a rotation period of $24^{\text{h}} 0^{\text{m}} 53^{\text{s}}$ round an axis inclined some 70° to the plane of the orbit. But these objects were illusive. Yet Schröter had called attention to two features which were subsequently confirmed: (1) that the phase was always smaller than it ought to be theoretically; and (2) that the S. cusp looked very often blunted. This last phenomenon was well explained by Schiaparelli as due to the presence of some dusky area near the S. pole, although he did not draw any such marking on his map of the planet.

At about the same time as Schröter, Herschel could detect no spots on Mercury. Prince, in 1867, Birmingham, in 1870, called attention to their observation of white areas, while Vogel seemed to recognize other markings. In 1879 Flammarion saw no spots; and from 1876 to 1881 Trouvelot could only catch a glimpse of a white area at the N. cusp of the crescent phase.

In 1882 De Ball drew a curved dusky shading on the morning phase, which Schiaparelli later identified with one of the markings seen by himself; and, in the same year, the eminent English observer, Denning, saw several spots, which I was enabled to confirm in 1927, and from which he concluded that the rotation period was about 25^{h} .

Between 1881 and 1889 Mercury was scrutinized in broad daylight by Schiaparelli with his customary perseverance and with the start-

¹ Reprinted by permission, with a few additions by the writer, from *The Journal of the Royal Astronomical Society of Canada*, vol. 27, no. 10, December 1933.

ling result that the period of rotation was found to be equal to the period of revolution, the planet completing a rotation of $87^d.969256$ round an axis almost perpendicular to the orbital plane.

It is generally stated that Lowell did confirm the conclusions of Schiaparelli. Yet in his 1896-97 map he does not show a single marking observed at Milan, or elsewhere, but only an enormous number of illusive blackish, linear canals, some perpendicular, others parallel, others inclined to the plane of the orbit of the planet.

On August 31, 1900, Barnard, using the 40-inch at Yerkes, detected in broad daylight "3 or 4 large darkish spots, very much resembling those seen on the Moon with the naked eye," adding that "one of these dark markings south preceding the center of Mercury was specially noticeable."

In 1907 and the years following, Jarry-Desloges and Fournier drew some dusky spots of Schiaparelli's chart, which Sormano believed to have been probably confirmatory of the long rotation period.

Five years later, Danjon, using a $7\frac{1}{2}$ -inch refractor in Paris, depicted admirably some real dark markings on the evening phase, confirming Schiaparelli, and thus succeeding with a modest instrument located in the smoke and dust of the great city there, where Lowell had failed with a powerful telescope in the elevated and so highly vaunted tablelands of Arizona.

The conclusions of Schiaparelli met a cool reception. Yet a handful of astronomers, among them C. A. Young, E. W. Maunder, and A. C. D. Crommelin, entertained but little doubt as to the accuracy of the results of the Italian, while the majority of scientists opposed to them a sturdy skepticism. It was thus only 4 years ago that Graff wrote that almost nobody now believed in the 88-day rotation period of Schiaparelli, controverted, as he thought, by the radiometric measures executed on the small disk of the planet. I never accepted the deductions drawn from the interesting indications of the thermocouple on the planets; and, in the case of Mercury at least, my distrust was proved to be founded by the unexceptionable evidence of observation.

Prudence naturally prompted me to have no opinion on the rotation period of that planet since I had not studied it telescopically; but, convinced that the powerful refractor of 33 inches aperture at Meudon could easily help to solve the mystery, I asked my director, M. Deslandres, for permission to use that instrument occasionally on Mercury in daytime—a demand which was favorably received by that most distinguished astronomer, and for which I wish to express here my feelings of deep gratitude.

The planet was thus followed near the meridian during the summer months of 1927, 1928, and 1929; and it was soon obvious that its markings, which were often seen quite distinctly, appeared fixed with regard to the terminator for hours together on the same day. Yet they showed, day after day, a pronounced movement of libration in

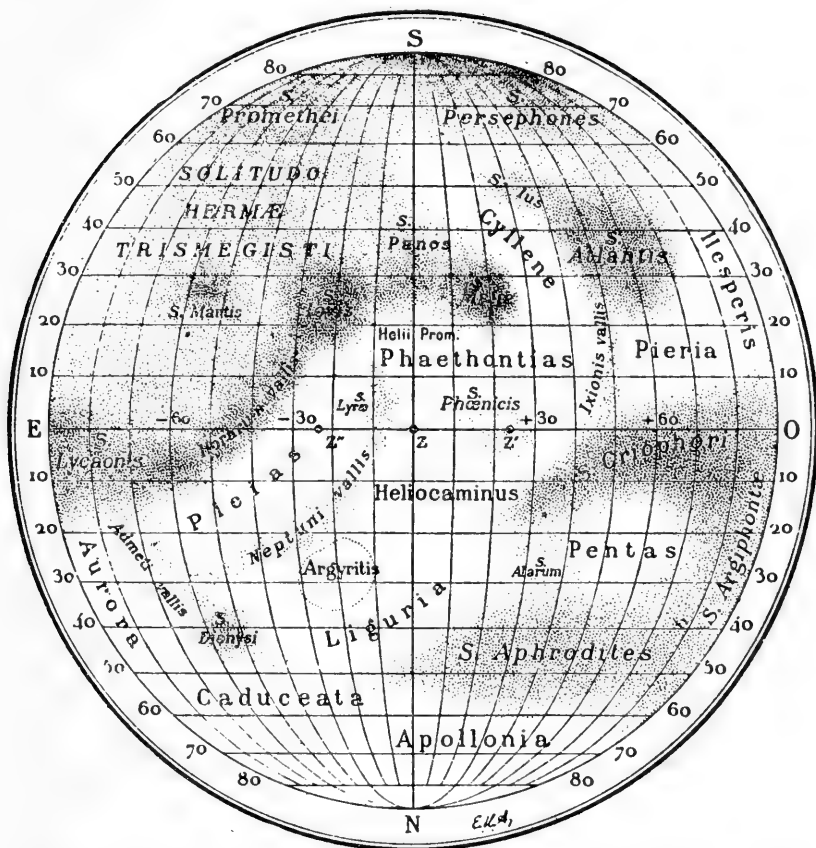


FIGURE 1.—Chart of Mercury. Embodying all the markings observed on the planet with the 33-inch Refractor at Meudon, in 1927, 1928, and 1929. By E. M. Antoniadi.

The central point, Z, is supposed to have the Sun at the zenith when the planet is in perihelion or aphelion; but as the projection is not an orthographic one, the chart does not give the approximate appearance of Mercury in superior conjunction with the Sun.

The letter *S.* stands for the initial of the Latin word *Solitudo*, wilderness; and the abbreviation *Prom.* stands for *promontorium*.

Argyritis is a bright white region, and was discovered in 1882 by the English astronomer, W. F. Denning.

longitude, such as would be necessitated by a uniform rotation of Mercury in a period equal to that of the revolution round the Sun. The axis was found almost perpendicular to the plane of the orbit, its inclination not reaching 7° . Here, then, we had a complete vindication of the conclusions of Schiaparelli.²

² I must state that a very close scrutiny of Venus near the meridian for many months in 1928 with the large telescope has convinced me that Schiaparelli's period of 225^d

My results are embodied in the figure accompanying this paper. A closer scrutiny with the large telescope, and with better definition under a high Sun, would have revealed a much more detailed structure; but the present map gives a satisfactory view of the most important markings seen by me with certainty on that desolate world.

The color of Mercury looked at daytime in the 33-inch almost comparable with that of the Moon in twilight. The planet appeared yellowish with a slight roseate tinge on the azure of the sky; while a distinct neutral-gray hue was characteristic of its dusky areas.³

With the view of avoiding the use of periphrases in the description of the spots, I have given names to the latter, generally drawn from the Greco-Egyptian mythology of the god Mercury. A few names were inspired by the desert state and tremendous heat prevailing on the planet; and I deemed it a duty to christen a bright area by the name of the antique *Liguria*, in pious remembrance of Schiaparelli, born at Savigliano, for his truly wonderful discovery of the chief spots and slow rotation of Mercury with a small telescope.

The dusky markings of the planet appear larger in the 33-inch than in the telescopes of the Italian astronomer—a fact due to diminished diffraction in the big glass, and one, too, which yields a precious independent proof of the reality of the markings in question.

The largest of the gray spots was named "*Solitudo Hermæ Trismegisti*", or "*Wilderness of Mercury the Thrice Greatest*"—a fabulous personage, believed by the Greeks and the Egyptians to have invented all sciences, including astronomy. This marking was discovered, among others, by me at Meudon; it had not been seen previously on account of its faintness, and I have shown that medium-sized instruments do not reveal pale half-tones on the planets.⁴

The dark area named *Solitudo Atlantis*, to the right of my map, is certainly much larger now than when it was first drawn 53 years ago. Yet the reality of this apparent change must be considered with the utmost diffidence, as vegetation seems impossible on a world where the temperature rises at least 200° above the zero of the Centigrade scale.

rests on no decisive spots, but on an effect of contrast. The faint markings seen by me on Venus were manifestly atmospheric and variable from 1 day to the other. A calculation of the solar tides on Venus has shown me that her rotation was slackened only twice as much as that of the Earth. Should the absence of a satellite constitute an indication of a slow original rotation (which is doubtful), then the neighbor planet may have a rotation period extending over months, which seems to agree with my observations. In fact, definite spots appeared fixed here several times during more than 3 hours.

³ Schiaparelli found that these spots had a pale brown tinge. This I could not confirm, in spite of the great superiority of the large instrument in showing color. Mars, Jupiter, and Saturn display wonderful hues in it; but the dark spots of Mercury always appeared to me quite as colorless as the Maria of the Moon.

⁴ Mars Report for 1909, in Mem. British Astron. Assoc., vol. 20, p. 30.

An analysis of past observations has shown me that all the most important spots drawn by De Ball, Denning, Schiaparelli, Jarry-Desloges, Fournier, and Danjon are confirmed by my own observations; and that the principal markings of my map have been partly confirmed with the 33-inch by Messrs. Ritchey, Lyot, Burson, Baldet, Grenat, Roger, Mlle. Roumens, and by M. Swings, of the University of Liège, in Belgium, observing with me Mercury in the large instrument.

We thus have the converging evidence of many hundreds of mutual, independent, confirmations of the existence of definite spots on Mercury by several well-trained observers, and this always, without exception, in the positions necessitated by a period of uniform rotation equal to the period of revolution. Hence the 88^d rotation of the planet is now demonstrated to be established on an immovable basis.

The idea of a rapid rotation, of some 24^h, rests merely on analogy with the kindred rotation of Mars and of the Earth; and, apart from the decisive conflicting evidence of observation, it has the further disadvantage of ignoring the important action of the bodily tides. Now, I have shown that Mercury is with reference to the Sun in a position comparable with that of Iapetus with regard to Saturn;⁵ and we know, since the days of Cassini, that Iapetus, apart from his librations, presents always the same face to Saturn. The mean distance of Iapetus to his primary is 62 mean radii of Saturn; and the mean distance of Mercury to the Sun is 83 solar radii. But the density of the Sun is double that of Saturn; and, applying the sixth power law, which governs the frictional force slowing down rotation, we find that Mercury, as above stated, is with the reference to the Sun in a comparable position with that of Iapetus to Saturn. The duration of such tidal actions comes here into play, and somebody may ask if the Sun is as old as Saturn. A cosmogonist, skilled in the arts of grasping the exact manner in which the various globes of the universe were begotten, can alone clear up that mysterious question.

The application of the sixth power law to the satellites has further enabled me to demonstrate that all those bodies known up to 1893 show, apart from their librations, always the same face to their primaries.⁶ The problem had to be set in a very particular way, to which I was led by observation; and that is the reason why the law governing the rotation of the satellites had eluded the penetration of such profound mathematicians as Henri Poincaré and Sir George Darwin.

The same law will enable us to understand the very reason of the fundamental difference existing between the rotation of the planets and that of the principal satellites; expressing distances in radii of

⁵ Letter to Mrs. Maunder, *Jour. British Astron. Assoc.*, vol. 39, p. 86, 1928.

⁶ *Bull. Soc. Astron. France*, vol. 43, pp. 385-398, 1929.

the primaries, we find that the satellites had their rotation annulled because they were too near their planets; whereas the planets, excepting Mercury, have preserved the independence of their rotation because they were far too distant from the Sun.

Another interesting question is raised by the existence of an atmosphere around Mercury. That gaseous envelop, like the one surrounding Mars, is absolutely invisible; but the frequent presence of cloudy veils over the markings of the superficies constitutes a solid proof of its existence. The clouds of the planet were discovered by the acuteness of Schiaparelli, who found that they often appear as white streaks on the limb, and that they also veil the dark areas, being curiously more frequent on the evening than on the morning phase. The Italian astronomer compared these veils to the clouds of the Earth—a natural, though at present impossible, assumption, as will soon be seen. Yet, excepting this comparison, my independent results have entirely confirmed the statements of Schiaparelli on this question of the atmospheric veils of Mercury. The limb of the planet often showed to me temporary, irregular, whitish arcs of cloud, stretching sometimes over 3,000 miles in length. Toward the central regions, these veils tended to become invisible, their presence being indirectly revealed by the temporary pallor, or invisibility, of the subjacent markings of the surface. It was rarely that a spot belonging to the superficies would preserve its intensity unimpaired for many successive days; and the veils in question presented all the degrees of condensation, from the greatest rarefaction up to an opacity which completely obliterated dark areas of the soil measuring more than 2,000 miles across. The changes were sometimes so rapid, that a spot of the length just mentioned, visible with its real intensity through a clear Mercurian air one day, would be utterly invisible 24^h later, and conversely. Very often the dark areas had their intensity locally diminished for weeks, with an alternate succession of various degrees of pallor, extinction, and final return to their normal appearance. In the course of my inquiry, the hooked dark spot to the right of my chart, named "*Solitudo Criophori*", was much more often rendered invisible by local veils than any other marking.

The clouds of Mercury are much more frequent and more obliterating than those of Mars, whose nature is, however, quite a different one.

It is certain that these veils cannot be composed of droplets of water or of particles of ice, like our own clouds. The enormous heat radiated from the Sun renders the existence of water in the liquid state on the sun-lit hemisphere of Mercury impossible, while the deductions of Johnstone Stoney from the kinetic theory of gases make the presence even of aqueous vapour extremely doubtful in

the atmosphere of that world. Meantime the low albedo of these clouds, which does not exceed 0.2, is quite different from that of our cumuli at 0.7, so that the only admissible explanation of the atmospheric veils of Mercury is that they are probably due to minute particles of dust, raised by the violence of the winds above the gloom of the dark, scorched, and desolate surface.

It has been shown by the variation of light with phase that Mercury must have a very rough and uneven soil; and his low albedo seems to indicate the presence, on his superficies, of eruptive rocks, of basalt and dark lava. The varying distance from the Sun must tend slowly to disintegrate the rocks exposed to his heat, and this process of destruction must be particularly active along the borderland of the terminator, where the wilderness is exposed to awful variations of temperature, ranging, indeed, over hundreds of degrees Centigrade.

"Mercury", says Dr. Crommelin, "is probably a parched desert, with nothing to mitigate the intense glare of the Sun on its day side, seven times as fierce as we receive on Earth."⁷ Professor Aitken rightly considers that "the little planet is not fitted to be the abode of life"⁸—a conclusion to which the late lamented E. W. Maunder had independently arrived when he wrote that "the conditions of Mercury are so unfavorable for life, that, even if this remarkable relation of rotation period to revolution did not hold good, it would still be impossible to regard it as a world for habitation."⁹

⁷ *The Star World*, pp. 82-83.

⁸ *Journ. Roy. Astron. Soc. Canada*, October 1911.

⁹ *Are the Planets inhabited?*, pp. 116-117.

BRITISH POLAR YEAR EXPEDITION TO FORT RAE, NORTHWEST CANADA, 1932-33¹

By J. M. STAGG

[With 2 plates]

The first three-quarters of last century were years of tremendous activity in polar and especially Arctic exploration. Led by such men as McIntock, Franklin, Ross, Barrow, and many others, expedition followed expedition for a long series of years. Naturally, a great deal of novel and extremely interesting observational material was gathered in the course of these expeditions, but, on the whole, and very largely because of the sporadic and uncoordinated nature of the activities, the truly scientific results accruing from so much splendid effort and so great expense were considered meager.

Hence it came about that, around 1875, a proposal was put forward by Count Weyprecht, of Austria, for the arranging of a number of simultaneous expeditions which would cooperate on a uniform plan over a full year. The result was the organization of what has come to be known as the First International Polar Year, 1882-83, when 14 expeditions were in the field, 12 to high northern latitudes and 2 to the Antarctic. Great Britain collaborated with Canada in establishing a station at Fort Rae, a trading outpost of the Hudson's Bay Co. on the North Arm of the Great Slave Lake. From that expedition Captain Dawson, R. E. (who in 1932 died as Colonel Dawson), with his party of engineers trained as observers and with the assistance of Canadian canoe men and guides, brought back results whose value and usefulness have not been fully explored to this day. During that First Polar Year all the stations were fully equipped with such instruments as were then available for a comprehensive series of observations in meteorology and terrestrial magnetism; they worked on a common prearranged plan.

Practically and scientifically, from the point of view of the international collaboration as well as Britain's share in it, the year's activities were completely successful.

¹ The G. J. Symons' Memorial Lecture delivered on Mar. 21, 1934. Reprinted by permission from the Quarterly Journal of the Royal Meteorological Society, vol. 60, no. 256, July 1934.

Since 1882 progress in meteorology and cognate lines of geophysical investigation—though probably less spectacular than in some of the other domains of physical science—has been very great. A vast number of new problems have arisen; the fields of inquiry and observation have grown ever wider—and higher. In 1882-83 none of the expeditions, so far as I know, carried out any upper air work. Their efforts were necessarily confined to surface meteorology. In terrestrial magnetism hourly readings by eye of instruments designed to give the three major elements in the earth's magnetic field were as much as the expeditionary technique of those days allowed. And the description of the state of the sky at each hour covered the demands of the time in auroral observations.

In recent years, however, meteorologists have been requiring more observations over an increasingly wide area and more detailed data on the characteristics and circulation of the atmosphere up into and beyond the stratosphere. Again, the study of states of disturbance and quiet in the earth's magnetic field has shown that one observatory can no longer be considered representative of a large area of the earth around it; the changes in the magnetic field are fine structured in space as well as in time, so that a close network of magnetic stations equipped with continuously recording instruments is now needed. And for observations in aurora to serve their best purpose in linking up with the associated magnetic disturbance on the one hand and the variations in height and intensity of ionization in the several conducting layers of the high atmosphere on the other, precise determinations of the position of the aurora in space are required from as many and as widely distributed localities on the earth's surface as possible.

Thus we see that from all angles of meteorology, terrestrial magnetism and auroral investigation, a fresh Polar Year program was urgently required on a much more intensified and extensive basis than that of 1882-83.

The suggestion, put forward by Admiral Dominik of the Deutsche Seewarte, Hamburg, to hold the repetition in 1932-33—the jubilee year of the First Polar Year—was therefore generally welcomed. An International Commission representative of the meteorological services of many countries was set up to organize the project on a world-wide basis, and national committees were convened to carry out the general recommendations in each separate country. In Britain the national committee had representatives from the Royal Societies of London and Edinburgh and six other interested institutions, including the Royal Meteorological and Royal Geographical Societies. Col. Sir Henry Lyons became its chairman and Dr. Simpson its secretary. Despite the grave financial stringencies of the times, funds to the extent of £10,000 were put at the disposal of the

committee by the Government through the Air Ministry, and large and generous donations were made in instrumental and foodstuff equipment by upwards of 50 manufacturing and wholesale firms.

For obvious reasons, it had been one of the guiding principles of the international program that, as far as possible, the stations occupied 50 years' ago should be reestablished, with, of course, as many additional ones as possible to complete the circumpolar network. And, further, though it was true that special efforts were to be made in high latitudes, where systematic observational material is at once most scanty and most important, the program of meteorological, auroral, and magnetic work was to be intensified throughout the world.

It reflects great credit on the efforts of the International Polar Year Commission and especially on its most enthusiastic and energetic president, Dr. la Cour, director of the Danish Meteorological Service, that in spite of the incidence of the world-wide financial crises just at the time when preparations were in progress, some 46 different countries have taken part in the Polar Year activities, 23 of which have been able to set up special stations either in their own territory or that of other countries more suitable for the work. A map showing the distribution of Polar Year stations is reproduced in figure 1.

To this general program Britain's contribution has been fourfold:

(1) By collaboration with her permanent and regular meteorological stations and observatories, including ships at sea.

(2) By organizing a scheme of special auroral observations in Scotland and the northern islands—a work largely in the hands of the Royal Society, Edinburgh.

(3) By subsidizing a party under Prof. E. V. Appleton for making an extensive, novel, and very valuable series of observations of conditions in the ionosphere over Tromsø.

(4) By reoccupying the station at Fort Rae, established 50 years ago.

In the party of 6 selected by the National Committee for the work in Canada, 4 of us, Messrs. Morgans, Sheppard, Grinsted, and I, were from the Meteorological Office staff; the fifth, Mr. A. Stephenson, from the geography department, Cambridge, had had experience of Arctic work with the British Arctic Air Route Expedition to Greenland in 1930-31; and Mr. Kennedy, our sixth member, acted as our steward-mechanic. All six of us were very thoroughly examined by the Air Ministry medical staff before being accepted, since our station would be far from skilled medical aid for at least 14 months and our personnel was too small to include a doctor. Mr. Grinsted and Mr. Stephenson had, however, undergone a short course in first aid against the cruder contingencies which

might arise. Fortunately, their skill in this direction was never seriously tested; except for one or two minor mishaps, all of us kept good health and fitness throughout our stay in Canada.

Sailing from Southampton to Montreal about the middle of May 1932, we journeyed by Canadian National Railways to Edmonton in Alberta, and thence north for 300 miles to MacMurray, the end

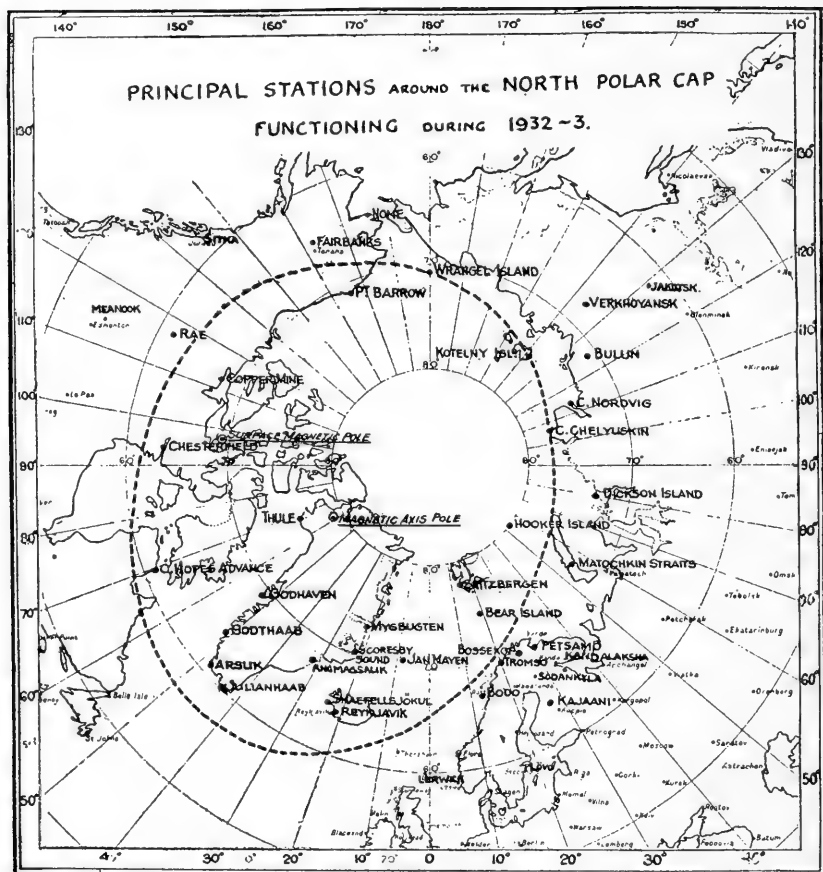


FIGURE 1.—Distribution of main observing stations around the North Polar Cap. The dotted line indicates the supposed position of the zone of maximum auroral frequency deduced from observations before the Second Polar Year.

of the once-weekly railway service, and starting point of the river and lake transport of the Hudson's Bay Co., used for distributing stores to its trading stations in the Mackenzie River district of northwest Canada. In the shallow-draft, stern-wheeled boat, *Northern Echo*, we chugged our way northward down the river Athabaska, across the lake of that name, and then down the Slave River till we came to Fort Fitzgerald, where 16 miles of rapids make the river impassable. Our freight, comprising 16 tons of

instrumental equipment and foodstuffs, had gone ahead of us, but we caught up on it at Fort Smith at the lower end of the rapids along which it had been transported by a portage road. From Smith we continued north down the Slave River and across the Great Slave Lake till we were some 1,000 miles north of Edmonton. In the early years of this century the site of the trading post at Fort Rae had been moved 25 kilometers farther north into the Marian Lake extension of the Great Slave Lake. The added facilities offered by staying near the trading post made us choose the new Rae for our main base. During the period of our stay, however, a site almost identical with that of the 1882-83 expedition was used as a subsidiary station in communication with the main base for photography of aurora and also in the two summers of our stay for comparison observations in terrestrial magnetism.

We were fortunate in finding the north arm of the lake free from ice at an unusually early date and so arrived at the scene of our Polar Year activities by mid-June.

Every minute of our time before August 1, 1932, the official date when all the Polar Year stations were due to start their activities, was occupied with the building of huts, setting up of instruments, and getting them into proper working order. By arrangement with the Hudson's Bay Co. we were saved the building of dwelling and main observatory huts, but our magnetic work demanded two huts of special type, one for the continuously recording magnetographs and another for the control observations. Both of these had to be free of magnetic material, and, though our standard magnetographs could be completely self-compensated for temperature changes, we thought it best to erect them in a chamber with as small a daily range of temperature as possible for double safety.

A custom among the Dog Rib Indians in that part of Canada of deserting any dwelling-place where a member of a family has died, gave us a log shack which, when denuded of the large quantity of iron nails used by the former owners for supporting the "wall-paper", formed a very serviceable outer shell for a multiple-walled, thermally insulated chamber we built within. The outer walls of this hut were subsequently mudded and heavy turf was banked up around them, so that by the time the autumn snows had made still another covering the insulation of the magnetograph chamber within was very satisfactory. In this chamber we erected three complete sets of magnetographs, each set recording photographically, continuously and independently the variations in the three components of the earth's magnetic field. One set, the standard, was of the very recent pattern designed by Dr. la Cour, Copenhagen; the second set, acting as a subsidiary and run at low sensitivity, was loaned by Greenwich Observatory; and the third, also of the Copen-

hagen type, was run at quick speed for giving accurate times of incidence of special perturbations in the field, such as sudden commencements of magnetic storms.

Until a year or two ago, when this quick-run magnetograph was perfected in Denmark, it was impracticable to specify times of perturbations on magnetic traces to a greater accuracy than 1 or even 2 minutes, so that such questions as the mode of propagation of world-wide sudden commencements—whether they appeared simultaneously over the earth, whether they traveled from east to west, or whether they were propagated along meridians—could not be decided with certainty. Now, among disturbances in the earth's magnetic field during the Polar Year, a well-marked sudden commencement on April 30, 1933, heralding a big disturbance on May 1, was recorded on the quick-run magnetographs at most of the Polar Year stations. Preliminary measurements show that, within about 2 seconds, this movement was recorded simultaneously at places as far distant as Copenhagen, Thule in northwest Greenland, Rae in northwest Canada, and probably also at Huancayo in Peru and Watheroo in Australia. Thus an early result of the Polar Year activities may be to throw important light on this long discussed question and therefore, directly, on the mechanism producing magnetic storms.

The electric light for the recording mechanisms of this magnetic apparatus was supplied by a Delco motor generator and accumulator battery we took with us for the purpose.

Of control magnetic instruments we had a double set representing the old and new systems of magnetic observing. A Kew magnetometer and dip circle served as comparison checks and also for parallel work at the old Fort Rae substation, where magnetic observations had to be carried out to determine the secular change since 1882; while a Smith magnetometer and dip inductor were used as the standard instruments for determining horizontal force, declination, and inclination at the main base. The use of electromagnetic methods for determining the value of the earth's magnetic field is of special advantage in such a place as Rae, where magnetic disturbance is so frequent and on such a large scale. Observations which took the best part of an hour by the older technique now require only a few minutes—provided everything goes as it should.

Our meteorological equipment was very complete. Almost every instrument was run in duplicate so that records might be maintained complete in case of clock stoppage or unforeseen accident. And such safeguards proved necessary, especially where clocks running out of doors were concerned. Expecting trouble with the temperature and humidity recorders in the Stevenson screen in the winter months, we

took clocks which had been specially designed to function at low temperatures; we also had some lubricating oil alleged to have a very low freezing point. But the oil froze in its bottle when put outside the door in midwinter, and the low temperature clocks gave much more trouble than, and were indeed ultimately discarded in favor of, ordinary clocks used at meteorological office stations, after they had been completely overhauled and cleaned of every trace of lubricant. For future work where clocks are required to run continuously and regularly at low temperatures, much more attention should be paid to the design of the balance wheel and escapement movement.

Our Dines anemometer erected over the main observing hut roof worked very satisfactorily. Instead of galvanized iron tubing to convey the pressure and suction surges from the head to the recorder, we used hose piping. This stood up to the cold admirably and much eased the process of erection. Only once or twice in the early days of winter had we difficulty with the water of the recorder freezing. A cupboard into which we could put a Valor heating stove was built completely around it, and when the temperature of the hut showed signs of falling below 32° F., the lighting of the stove insured safety. A greater cause of trouble in the running of the recorder was the drying of the pen. Throughout the winter months, when there was probably no unfrozen water surface nearer than the Arctic Ocean, to the north, absolute humidity generally was very low, and this, added to the dry heat produced by a large iron box-stove burning wood fuel, made the air in the hut so extremely dry that many ordinary operations became difficult. In particular, the capillary action of the surface of the anemograph record in drawing the ink from the pen seemed almost to be prohibited. A great many remedies were tried, but none was wholly satisfactory.

The recording of snowfall has its own pitfalls. Even to estimate the total fall over a 24-hour period is difficult where the snow is fine, dry, and powdery, and so liable to drift with the slightest wind. We had a continuously recording snow recorder of the Hellman-Fuess type as well as a rain gage converted into a snow gage, and two or three snow poles distributed around our station, but the days on which we got agreement between any two of these were exceptionally few. An attempt was made to estimate the drift snow by arranging a box with vertical circular opening and a system of baffle plates to be automatically turned into the wind, but the contributions to knowledge from this bit of our gear are probably negligible.

An important aspect of the meteorological program was our aerological work, and for that we required a considerable stock of hydrogen. The very long and expensive overland route to our station in Canada made the transport of hydrogen in cast steel cylinders

prohibitive, and to produce it by the calcium hydride process was too costly in the quantities we required. Captain Rogers, of the Royal Airship Works at Cardington, designed an apparatus for producing the gas by the interaction of hot caustic soda on finely granulated quartz. From the generator the gas passed through water traps into a reservoir bag, and from this it could be pumped by bellows into either the pilot balloons or ballons-sondes. An excellent piece of apparatus for its purpose in summer once its idiosyncrasies were known, this hydrogen generator could be the most capricious item of our equipment in the winter months. It was liable to do anything with little or no provocation or warning. A shower of boiling caustic soda was common; Mr. Morgans, in charge of the meteorological work, and on whom almost all of this aerological work fell, escaped miraculously on one occasion when the roof of the hut was blown up, and the windows out, and parts of the apparatus rendered more or less permanently hors de combat.

Pilot balloons were sent up at least once a day throughout the period of our stay at Rae, and the larger balloons with Dines meteorographs attached on days when the pilot balloons indicated that the upper air currents were likely to carry them into a part of the Indian reserve through which trapping and hunting trails mainly passed.

The recovery of the meteorographs was one of our very serious problems. For, except for the few Indian trails winding through the bush from Rae to the Barren Lands and Bear Lake trapping grounds in the north and down the lake shore toward the Yellow Knife estuary in the southeast, the country around our main base was almost completely uninhabited. To have attempted to hunt for the instruments ourselves, even if we had had double the personnel we actually had, would have been wholly impracticable because of the difficult nature of the bush country. And even the project—which we very seriously contemplated—of transporting all our aerological equipment 100 miles down to the main lake, we finally saw would not materially help our chances of recovery. So we were forced to rely on our pilot balloon and nephoscope observations (and these after all can tell us very little of where a meteorograph may be carried by the time it gets well into the stratosphere) indicating that, at any rate during the early stages of its journey, the ballons-sondes would be moving over areas where there was a chance of a few isolated Indians on the trail. To increase the chance of the meteorographs being found a long brightly colored tape was tied to each one and the Indians were encouraged to keep their eyes open for them by promise of a substantial gratuity. Further, by offering presents (illegally, as it turned out) from our small liquor store to the traders of the settlement to whom their Indian customers might bring the meteorographs, we hoped to encourage them to continue re-

minding the Indians of the value we put on the recovery of the instruments.

When we went out to Canada we were not sanguine of retrieving any of the meteorographs, but we hoped for two; and, alas, two only we got. Both of these were from balloons released in winter conditions when the air temperature was about -30° C., and both the records are fortunately very good. They show that in both ascents the instruments attained heights of approximately 16 kilometers, passing through a well-marked tropopause at 8.5 kilometers with a temperature about -60° C.

Since the meteorograph records are engraved on silvered plates which do not perish for many years, and since, too, the uncontaminated nature of the atmosphere in that part of Canada will help preserve them, there is always the chance that the remainder of our meteorographs which fell into the bush will yet be discovered and forwarded to us.

During the 13 calendar months of the Polar Year that ended on August 31, 1933, we continued complete meteorological observations according to the International Code every 3 hours, and during most months of that year observations of cloud every hour. The object in maintaining complete records and observations of all the meteorological elements was much less to collect data for the making of climatological averages than to be able to supply detailed information about the weather and conditions in the atmosphere at any time. This, along with similar information from other cooperating stations, would allow the general meteorological situation over wide areas to be reconstructed and investigated synoptically. The summary of our temperature records is, however, of general interest. This confirms our experience that the winter of 1932-33 at Fort Rae was characterized less by extremes of low temperature reached than by the protracted steadiness of the cold. The mean temperature for the 7 months ending April 30 was -20° C., the contributions to this mean from January and February being both about -31° C. On individual days the lowest mean was -40° C. Day temperatures during the short summer comprising the latter part of July and August not infrequently rose to 20° C. Over the 12 months ending September 30, 1933, the mean temperature at Rae was -7.3° C. compared with -6.2° C. for the corresponding period at the old Fort Rae station in the first polar year 50 years ago.

Observations in atmospheric electricity formed one of the other main subdivisions of our program of work, and these Mr. Sheppard had in his particular care. For the maintenance of continuous records of atmospheric potential gradient we used a Benndorf electrograph and a polonium collector. To make up for the rather quick

rate of decay of the polonium, additional collectors were fitted symmetrically to the boom throughout the year so that the rate of pick-up of potential remained not less than a safe limit. The control measurements of the potential gradient were made over a level stretch of rock using the Simpson stretched wire method. Twice a day whenever possible, at 9 h. and 15 h. local time, measurements were made of the air-earth current, using a Wilson guarding electrometer modified to incorporate a Lindemann electrometer, and of small ion content of the air by an Ebert aspiration electrometer, also modified by Mr. Sheppard. On almost all days while these measurements were being made the number of Aitken nuclei in the atmosphere were counted by an Aitken counter. During the spring months series of experiments were made over periods of 24 hours to determine the nature of the diurnal variation of the air-earth current, ion content, and Aitken nuclei, as well as of the rate of production of ions near the ground.

Though some of Mr. Morgan's meteorological instruments had been functioning continuously from July 1, it was nearer August before the magnetographs had settled down in their new quarters, but by the first of that month, the zero hour for the general Polar Year operations, all was in working order.

Since by that time the evenings were fast drawing in, we set about finding a means of maintaining communication between our main base and the substation, the site of the 1882-83 activities, 15 miles down the lake to the southeast. For a fourth and important item in our program was the simultaneous photography of suitable types of aurora at two ends of a base-line, to allow the height and orientation of the aurora to be measured from the apparent displacement of the same piece of aurora against its stellar background on pairs of synchronously exposed plates. To have the two-way communication which is almost necessary for this work, we had taken a supply of Silmalec wire made for us by the British Aluminum Co., and specially insulated by Henleys Cables, Limited. In its final form the wire weighed only about 23 pounds per mile. This we hoped to erect down the lakeside between the two stations, using the spruce and birch trees for support. But on detailed reconnaissance the shore was found to be so broken and irregular that to have followed the shore would have exceeded our length of cable, if not also our amateurish capabilities in erection of telephone lines. So we decided to wait till the lake had just frozen and in the meantime, that is between August and October, we used two small wireless transmitting and receiving sets. Though the simultaneous photographic work could, in default of other means of communication, have proceeded by this means with difficulties and inconveniences and probably much loss of effective aurora, we started to erect the tele-

phone line as soon as the ice on the lake was safe for working on. In the bush immediately behind the two stations the wire was hung from the taller spruce trees bared of their longer branches, and on the 8 to 10 miles of open lake, poles cut from spruce or birch trees along the lakeside and let into the ice sufficiently far to be frozen solidly in position, formed the bases of support. It was not practicable to lay the cable on the ice, partly because the high specific inductive capacity of ice would have amounted to earthing the cable as it became buried in the ice by its own weight, and partly because a winter trail for Indians passes up the lake between the two stations. The cable would very probably have been inadvertently cut by the passage of dog sleighs over it. In this work of cable laying we all had a hand, but Mr. Stephenson with his experience of dog-sleigh work gained in Greenland was invaluable in the open lake work of providing the poles from the lakeside, and Mr. Grinsted looked after all the technical details. Most of the erection was done at temperatures between -5° C. and -15° C.; it was a time of introduction to the experience of minor frost bites for some of us.

At the two stations the observers operating the cameras, designed for auroral photography by Professors Störmer and Krogness of Norway, were equipped with telephone headgear and breast-plate microphones, supplied by Messrs. Siemens, Ltd., so that the hands were free for manipulating the camera and plates. The microphones were fitted with auxiliary diaphragms of cellophane supported over the working diaphragm to prevent accumulation of hoar frost and ice crystals obstructing its movement. These cellophane diaphragms were exceedingly useful when working out-of-doors for periods of a few hours at temperatures down to -35° C.

Using the telephone system throughout the most rigorous winter months, and taking turns at manning the substation, we continued photographing aurora till the melting of the ice in spring undermined the supports and finally allowed the whole line to break up. Altogether we got about 4,700 pairs of photographs, of which probably 75 percent will be suitable for measurement.

In addition to this side of the auroral work an almost continuous log was maintained of all activity when it was dark enough to be seen. It was not infrequent in midwinter for aurora to continue uninterruptedly for 15 hours; and, despite the fact that the winter of the Polar Year was very near the minimum of the cycle of solar activity, aurora was observed at some time on every night almost without exception during the autumn, winter, and spring months when sky conditions were suitable.

During our 15 months' stay at Rae we had frequent contact with the outside world; indeed by wireless it could have been made continuous. In 1930 a reputedly rich discovery of gold and pitchblend

ores on the southeast shores of the Great Bear Lake to the north of us led to a "rush" of prospectors and miners to stake claims, so that, whereas up to that year Rae had been one of the most isolated trading posts of the Hudson's Bay Co., in 1930 it suddenly developed into a fueling station for aeroplanes passing from the south to the Great Bear Lake mining camps. By the time we left there was a fairly regular mail service during the months when planes could use either skis or floats, so that we had the very questionable benefit of frequent contacts with the outside world. During the summer months, and at Christmas and Easter too, the Fort is a meeting-place of the Indians of the Dog Rib, Bear Lake, and Yellow Knife tribes. These come in from their hunt to barter the fox, martin, muskrat, and other fine grades of fur for their crude necessities of existence. Though at times it was annoying to see these Indians gather round when our balloons were being inflated, and gloat with glee, so it seemed, with the prospect of seeing them burst, they were a wholly inoffensive set of people, simple and contented with their lot, wistfully sympathetic with, if not openly amused at, our activities.

We continued our observations at Fort Rae till early September 1933, so that we could have data covering very completely and continuously the main elements in meteorology, terrestrial magnetism, atmospheric electricity, and aurora for the full Polar Year. And now the less exciting, but none the less valuable part of the work remains to be done—the reduction of the data brought home and their adequate interpretation and discussion. This must be a matter of years. For it will not be till the corresponding material from all the other cooperating stations in the network functioning along similar lines during the Polar Year is available that the true significance of events at any one station can even be partially appreciated. Not till this is done will it be possible to say whether our work at Rae was successful. But whatever the verdict of the future may be, I, as the person privileged to lead the party, would like to take this opportunity of expressing my thanks publicly to my colleagues. On such a purely scientific expedition, with the numbers cut to a minimum and with such a full program of activities, every man had to pull his full weight, and at Rae every one did so. That the observational material and records we gathered are as complete as they have turned out to be is due entirely to the splendid support given me throughout the period of our stay in Canada.



Copyright photograph by Photopress, Ltd.

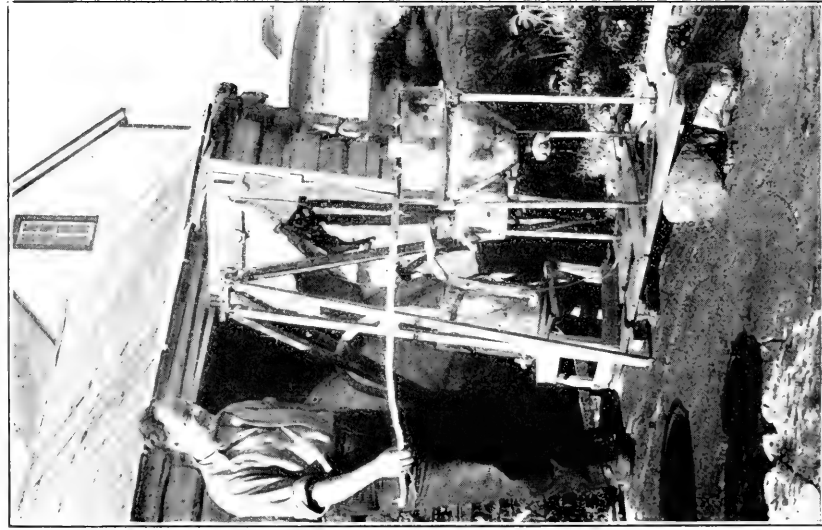
1. MEMBERS OF THE POLAR YEAR PARTY PHOTOGRAPHED AT KEW OBSERVATORY.

Reading from left to right: W. A. Grinstead, A. Stephenson, P. A. Sheppard, J. M. Stagg, W. R. Morgans, J. L. Kennedy.

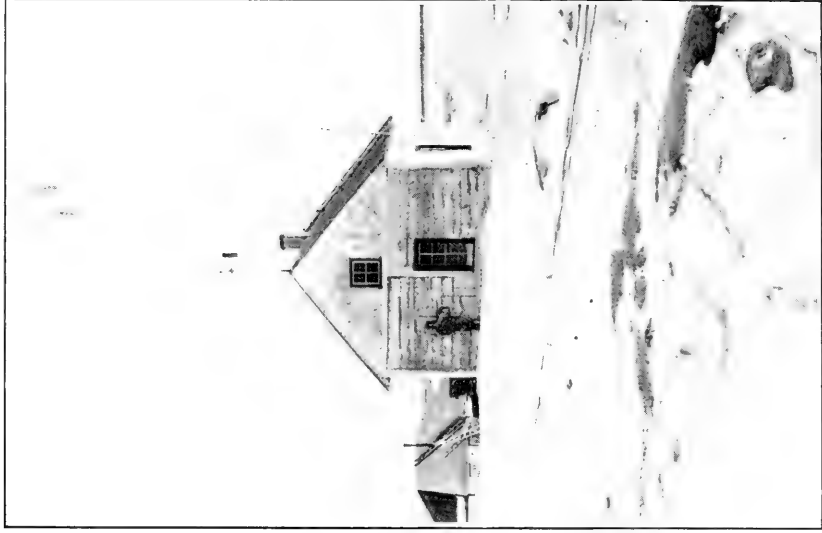


2. ONE CORNER OF THE MAIN METEOROLOGICAL HUT.

Showing (from left to right) part of the Dines anemograph and lower end of the mast, the Benndorf electrograph, the Ebert and Wilson instruments, and, on the right, the wireless transmitter and receiver used to maintain communication with the substation before the telephone line was erected.



1. MR. W. R. MORGANS WITH THE HYDROGEN
GENERATING APPARATUS.
The reservoir bag is inside the hut.



2. THE METEOROLOGICAL HUT.

PROTIUM—DEUTERIUM—TRITIUM THE HYDROGEN TRIO ¹

By HUGH S. TAYLOR

David B. Jones professor of chemistry, Princeton University

[With 3 plates]

Three months before the outbreak of war in 1914 an international scientific race had just been concluded. Soddy of Aberdeen had found that radio-lead from thorium sources had an atomic weight of about 208. Richards and Lembert in Harvard and Hönigschmidt in Vienna had shown independently that radio-lead from uranium sources had an atomic weight of about 206. Ordinary lead was known to be about 207. Soddy's concept that substances could exist with identical, or practically identical, chemical and spectroscopic properties but different atomic weights was established. Soddy suggested a name for such substances, isotopes, because, though different in mass, they occupied the same place in the chemist's periodic table of the elements. We know now that isotopes of the same element have the same net positive charge on the nucleus and the same system of external electrons. It is the net nuclear charge, not the mass of the nucleus, which determines the position in the periodic table.

Aston, who after the war returned to the Cavendish Laboratory in Cambridge, England, developed a mass spectrograph to determine masses of individual charged particles, and in November of the year 1919 supplied definite proof that the rare gas, neon, existed in at least two isotopic forms of masses 20 and 22. He thus extended the concept of isotopes to elements which were not radioactive in their origins. There followed a decade of activity in which, with the mass spectrograph progressively refined, an increasingly large number of elements were shown to be isotopically complex. There are, for example, 11 isotopes of tin. Some elements persistently proved to be simple. Carbon, oxygen, and hydrogen were among those so regarded at the end of the 10-year period.

¹ Reprinted by permission from *The Scientific Monthly*, vol. 39, pp. 364-372, October 1934.

Early in 1929 the complexity of oxygen was established by Giauque and Johnston of California, using a novel method of attack, by examining the absorption of light by air. They found absorption bands which were interpreted as belonging to compounds containing two new oxygen isotopes, one of mass 18 and a much rarer one of mass 17. Oxygen, of mass 16, had been used as the standard of mass reference for all the other elements both for historical reasons and because of its assumed simplicity. Its established complexity at once raised doubts as to the simplicity of carbon and hydrogen. In the case of the former, the doubts were resolved by the discovery, in 1929, of a rare isotope of mass 13 by Birge and King, again from a study of the band spectra of gaseous carbon compounds, among others that of carbon monoxide. Birge and Menzel calculated that discrepancies between the chemical atomic weight and the mass spectrograph value for hydrogen would be resolved if hydrogen contained about one part in 4,500 of an isotope of mass 2. It was this theoretical calculation which provided the spur for an experimental search for such an isotope by Urey, Brickwedde, and Murphy, jointly, at Columbia University, and the United States Bureau of Standards. They announced early in 1932 that, by fractional distillation of liquid hydrogen, the heavier isotope concentrated in the residue, and that its presence could be demonstrated by the appearance of a faint spectral line in the hydrogen discharge near the ordinary line of atomic hydrogen and spaced from it at such a distance as would be demanded theoretically for an atom with a charge of unity (that is to say a hydrogen isotope), but having a mass of 2.

Atomic weight determinations, mass spectrographic and light absorption measurements only demonstrate the existence, the relative abundance and the masses of isotopes. The practical identity of their chemical properties, emphasized at the outset by Soddy, had been utilized in the case of radioactive isotopes for chemical indicator purposes; the desirable goal of the scientist, the separation of the isotopes of an element and the separate examination and comparison of their properties, remained until a year ago unattained. An enormous amount of effort has been expended in the attempts at separation. These must be based on differences in properties which depend essentially on mass or on chemical reactivity. For a decade and a half prior to 1933 a variety of trials were made. Separation was attempted by fractional diffusion, by thermal diffusion, by centrifugal separation, by fractional distillation and evaporation at low pressure, by migration of isotopic ions under the influence of an electric current, by preferential excitation to photochemical reaction of one or other isotope using light absorbed by one and not the other.

The net success was vanishingly small. One or other method gave separations of one or two parts per thousand at such a prodigious expenditure of effort that the recovery of the pure components of an isotopic mixture seemed to be an unattainable objective. The hydrogen isotopes, of masses 1 and 2, represent the most favorable case, since the mass difference is 100 percent. Even in this case the problem seemed to be discouragingly difficult when it was shown that the fractional evaporation of 40 liters of liquid hydrogen until only two liters of gas remained raised the concentration of the heavier gas only to 1.5 percent. Hertz in Germany has separated the two isotopes by fractional diffusion through special porous material to yield the separate constituents spectroscopically pure. His method, however, only yields a few cubic millimeters of gaseous product.

The development which revolutionized the whole subject of isotope chemistry is due to the late Dr. E. W. Washburn of the United States Bureau of Standards. Washburn determined, late in 1931, to test the efficiency of electrolysis of water solutions as a method of concentrating the hydrogen isotopes. While his own experiments were in progress, he secured samples of water from commercial cells which had been used for several years in the electrolytic production of hydrogen and oxygen. Urey analyzed this water for him by the spectroscopic method and found an enrichment of the mass 2 isotope. Washburn himself found that the density of the water was greater than that of ordinary water by 50 parts per million, a further evidence of enrichment. As Washburn and Urey wrote in their joint communication "the above results are of great importance, for we now know that there are large quantities of water in these electrolytic cells containing heavy hydrogen in relatively high concentrations and, also, there is available now a method for concentrating this isotope in large quantities." Washburn's determination of the abnormal density of water from electrolytic cells will take rank with those classical determinations by Lord Rayleigh of the densities of chemical and atmospheric nitrogen, from which, with the work of Sir William Ramsay, there resulted the discovery of the rare gases of the atmosphere, helium, neon, argon, krypton, and xenon.

The isolation of the mass 2 isotope in approximate purity was not achieved by Washburn. The race was to the swift and to those richer in available resources of apparatus and men. In rapid succession, from the University of California, Princeton, Cambridge, England, Columbia University, Frankfort, and Vienna came records of the success of Washburn's method in producing water in which, with continued electrolysis, 30, 60, 92, 99.9 percent of all the hydrogen

atoms had a mass of 2 instead of 1. Since the mass of the molecule H_2O would be $2 \times 2 + 16 = 20$, whereas ordinary water would be $2 \times 1 + 16 = 18$, it is evident that, granting equal volumes of the two molecules, the new water might have a density of $20/18 = 1.11$. The experiments were followed by the changing density of the product, and it is now known that heavy water with hydrogen of mass 2 has a density of 1.1079 at 25°C . referred to ordinary water at the same temperature.

Shortly after the isolation was accomplished, Urey, Brickwedde, and Murphy christened the isotopes; hitherto this had not been necessary with isotopes, since there had been no chemistry of separate isotopes to be considered. The discoverers of heavy hydrogen suggested, for hydrogen of mass 1, the name protium, since this would conform with current usage of the name proton for the nucleus of the hydrogen atom. For the isotope of mass 2 they proposed the name deuterium, which, for the nucleus of this atom, suggests deuteron or, more briefly, deuton, the nucleus of mass 2 and unit positive charge. They also suggested that, if the isotope of mass 3 were discovered, the name tritium might be considered. These names have found general acceptance, except in England, where, following a suggestion from Lord Rutherford's laboratory, the name "diplogen" has been employed. The best excuse for this latter is that it gives "diplon" instead of deuton, which latter does not find favor with the English scientists who, with colds in their heads in winter time, may confuse deuton with the "neutron", the particle of mass 1 and zero charge. Considerable discussion has arisen as to the symbols to be employed. Previous custom has sanctioned H^1 , H^2 , and H^3 for the symbolic representation. There is, however, an increasing use of H for H_1 , of D for H_2 and of T for H_3 . Fortunately, D and T have not hitherto been used as symbols for any elements; also, D stands, equally well in England and elsewhere, for both deuterium and diplogen.

For the technique of preparation of pure heavy water or deuterium oxide, the Princeton procedure may be cited, since, in this manner, about 13 tons of commercial electrolyte corresponding to upwards of 50 tons of ordinary water have already been treated to yield approximately one pound of the purest heavy water. About 15 gallons of commercial liquor are electrolyzed daily to one-fifth volume in a battery of 960 cells using nickel anodes and iron cathodes. The residue is distilled to remove excess electrolyte, and the distillate after addition of alkali is passed to the second stage, a unit of 160 cells shown in plate 1, where it is again electrolyzed to one-fifth volume. These two stages concentrate the deuterium from 1 part in 1,600 to 0.25 percent, and 1 percent, respectively. From the third stage onward a modified form of electrolysis is employed in which

the evolved hydrogen (containing deuterium) and oxygen gases are recovered as water and passed back to the preceding stage of electrolysis. The experimental arrangement is shown in plate 2. The successive stages handle successively smaller volumes of water, the concentration of deuterium in which rises by steps from 1 percent to 4, 13, 35, 95, and 100 percent D_2O . The electrolytic fractionation factor is about 5, that is to say, the gas evolved is about one-fifth as concentrated in deuterium as the water from which it is evolved. Hence the separation that is achieved.

The product has unique and characteristic properties. Its density relative to ordinary water at $25^\circ C$. is 1,1079. It melts at $3.82^\circ C$. and boils at $101.42^\circ C$. It has a maximum density, not at $4^\circ C$. as with ordinary water, but at $11.6^\circ C$. It is 25 percent more viscous than ordinary water at $20^\circ C$. but has a smaller surface tension. Salts are less soluble in it by about 10 percent, and the electrical conductance of salt solutions is less than in light water.

There are three kinds of hydrogen molecules that can arise from light and heavy hydrogen atoms, namely, H_2 molecules, D_2 molecules, and the mixed molecule HD . To analyze mixtures of such gases a special mass spectrograph has been developed by Dr. Bleakney, of the Princeton Physics Department. It is evident that the molecules just discussed will give rise to ions of masses $2\lambda(H_2^+)$, $3\lambda(HD^+)$, and $4\lambda(D_2^+)$. In addition to these, atomic ions of masses 1 and 2 (H^+ and D^+) can also arise and, from these, triatomic ions (HHH^+) of mass 3, (HHD^+) of mass 4, (HDD^+) of mass 5 and (DDD^+) of mass 6. Bleakney's method permits him to sort out these various possibilities so that he can estimate how much protium (H) and how much deuterium (D) is present in a given sample. Figure 1 shows the results of one such analysis of a deuterium-rich sample.

Using such a method of analysis it has been found that the deuterium content of normal rain water is 1 part in 5,000 of the total hydrogen present. This is a much greater abundance of deuterium than is present in the chromosphere of the sun as spectra at the last eclipse definitely showed; it points to a tremendous preferential loss of light hydrogen during the earth's formation. The announcement by Lord Rutherford of the synthetic production of hydrogen of mass 3, tritium (T) by bombardment experiments of deuterium with highspeed deuterons lent considerable interest to a determination by the Princeton Physics Department of the tritium content of the purest deuterium oxide water prepared in the Frick Chemical Laboratory. With a new and specially refined mass spectrograph it has now been shown that our purest heavy water contains approximately 1 tritium to 200,000 deuterium atoms. This means that, in ordinary water, the tritium content is not more than 1 part in a billion. Tritium, therefore, becomes the youngest and rarest of all the isotopes yet discovered in naturally

occurring substances. Since heavy deuterium water costs, at a conservative estimate, \$5 per gram, it is evident that, with a 100 per cent efficiency of recovery of its tritium content, pure tritium water, T_2O , would cost at least \$1,000,000 a gram or water roughly 20 times the cost of radium. Such are the paradoxes of modern isotope chemistry.

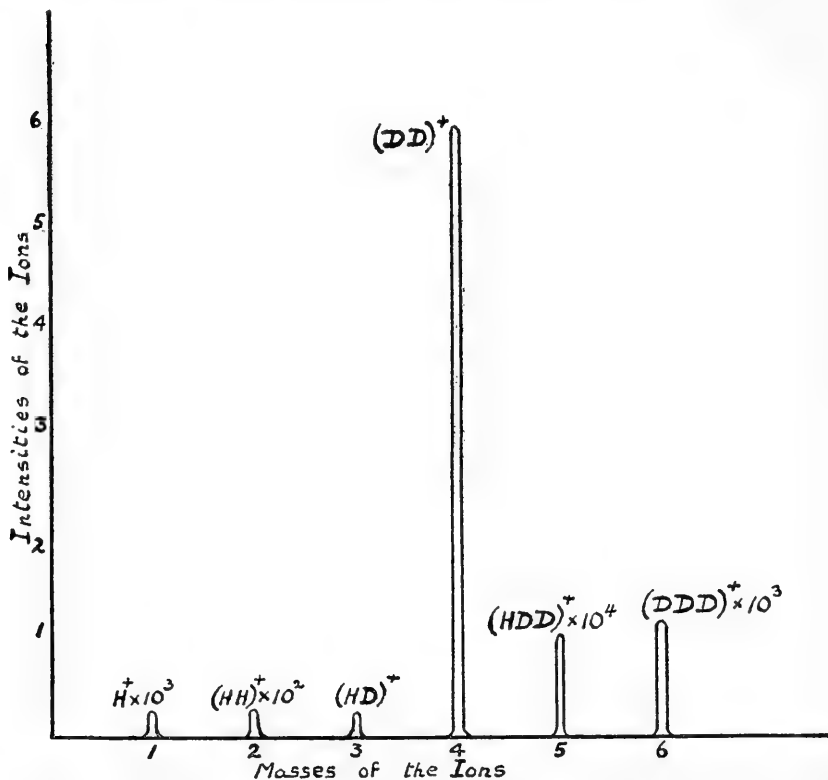


FIGURE 1.—Diagrammatic representation of an analysis by the mass spectrograph of a gas sample rich in deuterium. Each peak represents the abundance of the ion of mass given along the horizontal axis of the graph. The scale for the ions H^+ , $(HH)^+$, $(HDD)^+$, and $(DDD)^+$ is multiplied by the amounts shown against each peak to permit their representation on the same diagram in spite of their great rarity. The analysis yields 98 atom percent D and 2 atom percent H.

Using the same method of analysis it is possible to follow the rate of reaction of one isotope of a given element with its one isotope. It has been shown, for example, that H_2 molecules will react with D_2 molecules to form HD molecules at temperatures as low as that of liquid air, with catalysts such as chromium oxide and nickel, which are active in catalytic hydrogenation processes. These results indicate that the high temperatures necessary in industrial syntheses such as those of ammonia or wood alcohol are required not for the activation of the hydrogen but for the activation of the molecules with which the hydrogen has to react. If surfaces can be found as active toward these molecules as present available surfaces are with respect to hydrogen,

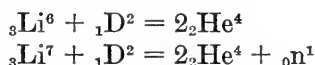
tremendous improvements would be possible in such industrial operations, under much simpler working conditions. Deuterium points the direction which research in technical catalysis must take.

Biologically, heavy water has proved to be of the utmost interest. Seeds of the tobacco plant do not germinate in heavy water. Fresh-water organisms such as tadpoles and guppies die quickly when placed in heavy water. Unicellular organisms, such as paramoecium or euglena, are more resistant, but are eventually killed. The luminescence of bacteria is modified in heavy water media, and the rate of respiration markedly reduced. Yeast ferments sugar in heavy water at only one ninth the rate in ordinary water. The enzyme catalase present in the blood stream and whose function it is to destroy hydrogen peroxide does so at only one-half the normal rate in 85 per cent heavy water. The action of the heavy water may be likened to that of a generally unfavorable environment leading to progressive changes in the cell. It would seem that the changes observed are the result of differential effects on the rate of biochemical reactions, examples of which have just been given in respect to enzyme reactions. The use of heavy water as an indicator of reaction mechanism in biological systems is evident from reports of recent English work in which it has been shown, by experiments conducted in heavy water, with organisms such as *B. coli* and *B. aceti*, that the present accepted mechanisms for their activity need to be modified in the light of results obtained with media containing deuterium instead of hydrogen.

The known compounds containing hydrogen are numbered in the hundreds of thousands. It is evident that an overwhelming program of research replacing hydrogen by deuterium is possible. Judiciously conducted, such a program will aim at the preparation of materials with which problems in physicochemical science may be tested. There are already the beginnings of such a program to be recorded. A number of exchange reactions between heavy water and different substances have thrown light on the problems of mechanism involved. Thus, ammonia gas, NH_3 , exchanges very rapidly with heavy water, D_2O , to give ammonia in which the hydrogen atoms are replaced by deuterium atoms to an extent depending on relative concentrations. In cane sugar, however, only about half the hydrogen atoms are readily replaced and these atoms are those present in the molecules as hydroxyl (OH) groups. Acetylene, C_2H_2 , and acetone CH_3COCH_3 , do not replace their hydrogens for deuterium in acid solutions or in plain heavy water but do so more or less readily in basic solutions. The former exchange indicates definitely the acidic nature of acetylene. The latter demonstrates that acetone in basic solutions exists partially in another form $\text{CH}_3 \cdot \text{COH} : \text{CH}_2$, which is acidic in nature due to the H attached to oxygen. In acetic acid CH_3COOH only the final acidic H is readily replaceable by D. In a compound

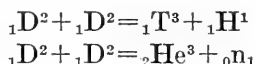
such as nitroethane, $\text{CH}_3\text{CH}_2\text{NO}_2$, the two hydrogen atoms next to the NO_2 group are replaceable by deuterium in basic solutions of heavy water. In this case the rate of reaction can be measured and it has been shown that H atoms leave this molecule more easily in the heavy water solutions than they do in light water solutions. Similarly, cane sugar is broken up by reaction with heavy water faster than by light water. In other reactions the velocity is slower in heavy water. The accelerating or retarding effect obtained is used by the chemist to decide the detailed picture of what is occurring in such solutions. With deuterium atoms as labeled hydrogen atoms, much can be learned about these detailed occurrences; and what is found for deuterium must also occur with hydrogen under the same conditions, even though, without the label, this cannot be demonstrated. Reactions of deuterium and deuterium compounds which are slower than those of hydrogen are due to the fact that the lowest energy states (the zero-point energies) of the former are less than those of the latter. To become equally activated, by heat or light, deuterium must receive greater increments of energy; *vice versa*, under equal energy conditions the deuterium compounds will in general be less reactive. In cases where this does not hold it is to be concluded that reaction does not involve molecules of the deuterium compound, but rather an atom or an ion. Comparative velocity measurements are, therefore, of great importance theoretically.

In the physics laboratory deuterium is being put to spectacular use as a projectile in atomic transmutation. Immediately after the isolation of deuterium the nuclei or deuterons were so employed to bombard lithium, the results showing them to be much more effective missiles than protons. Two processes are possible with the isotopes of lithium of masses 6 and 7.



The subscript to the left represents the nuclear charge; the superscript is the mass. Here also ${}_0\text{n}^1$ represents a neutron of zero charge and unit mass. Helium of mass 4 and charge 2 is the other product.

Experiments in Cambridge under Lord Rutherford suggested that deuterons could be used to bombard deuterons and produce new forms of matter. Here, also, there are two possibilities.



In the first, transmutation gives two hydrogen atoms, one of mass 1, the other of mass 3, in other words, tritium. In the second, the change is to a helium isotope of mass 3 and charge 2 and a neutron

of mass 1 and zero charge. Both of these changes have now been decisively demonstrated not only by the methods of Rutherford involving measurements of the tracks of particles; they have been employed to produce these rare isotopes "in quantity." Samples of deuterium after subjection to such atomic bombardment in apparatus shown in figure 2 and plate 3 have been found by the Princeton physicists to contain concentrations of tritium 40 times greater than that of the deuterium initially. Similarly, the production of helium isotope of mass 3 has also been shown. In each case the method of analysis involves the sensitive mass spectrograph already discussed. Deutons also are being used as the projectiles for the production of artificially radioactive light atoms, the new field of physics developed only this last year by M. Joliot and his wife, Mme. Curie Joliot, first with alpha particles, next with protons and neutrons, and now also with deutons.

That the pace of this scientific development is prodigious all must realize when they remember that only a year ago the deuterium isotope was not yet isolated. Today it has a still rarer brother, tritium; it has itself given rise to this and to other new isotopes, some radioactive, some not; it has made possible a new branch of chemistry, the chemistry of isotopes, which already has markedly enriched our knowledge of general and physical chemistry; it is a potent weapon of attack also on physiological and biological problems.

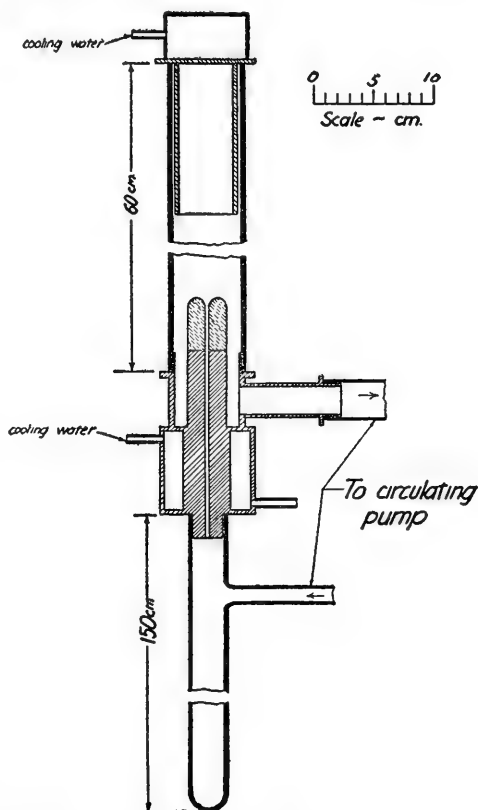
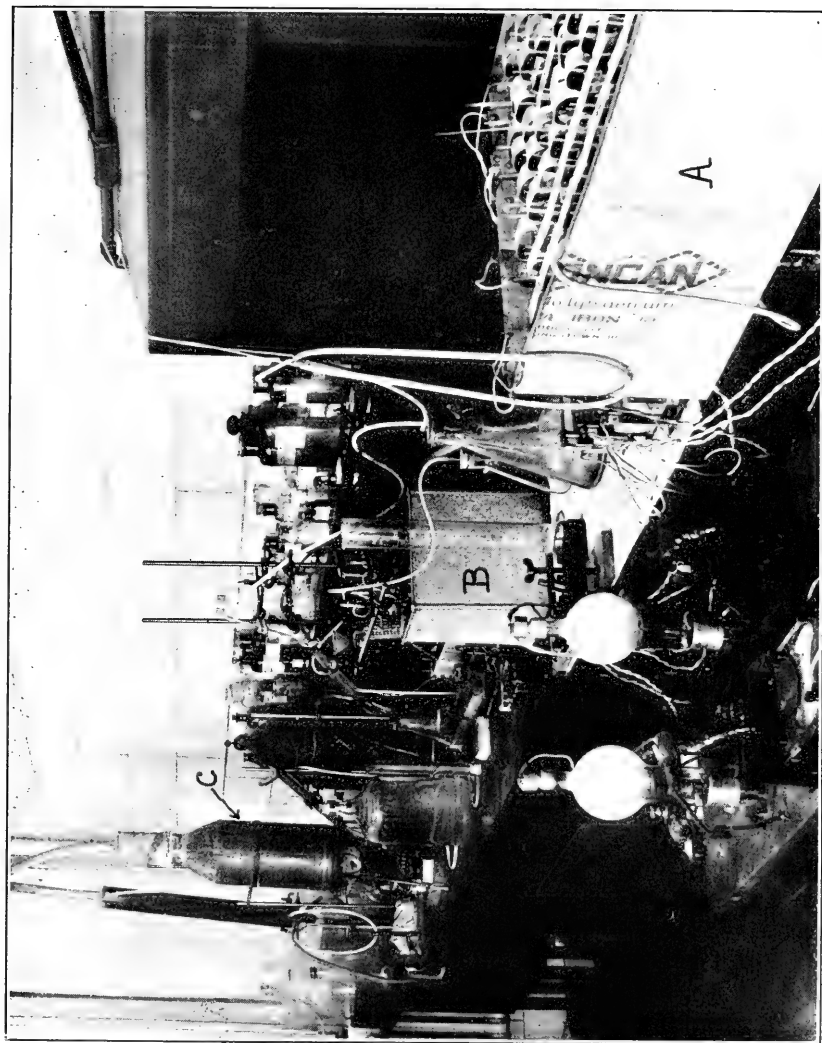
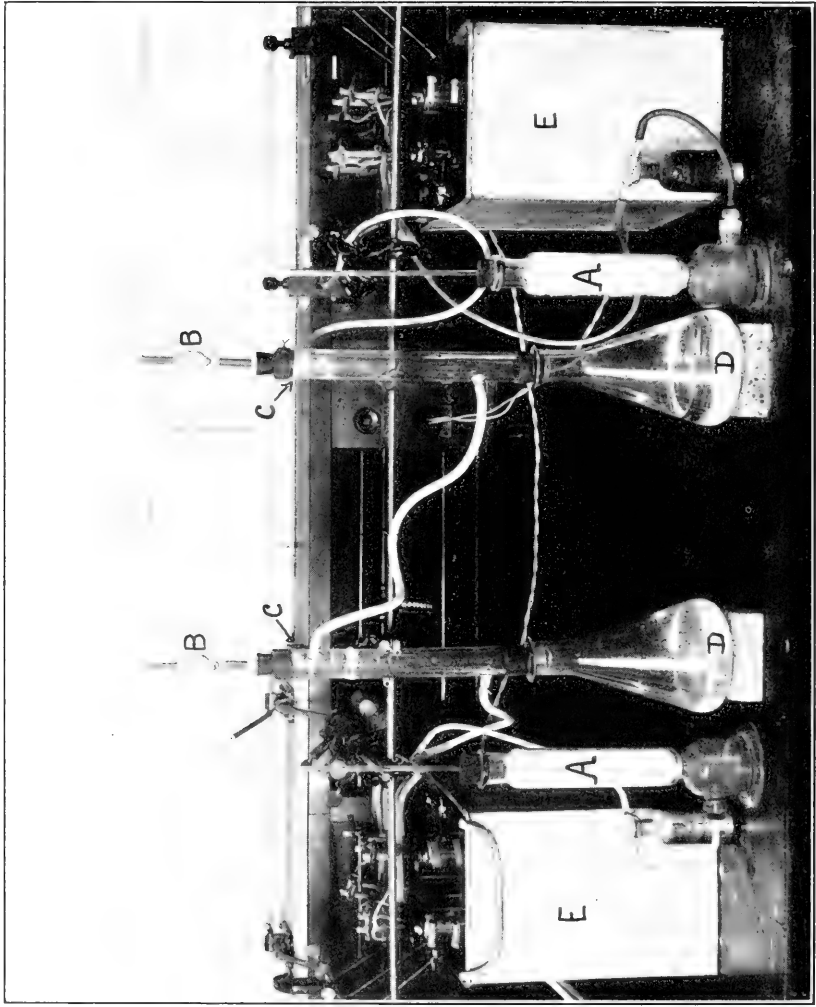


FIGURE 2.—Diagrammatic sketch of transmutation tube. Deuterium in the upper half is ionized and the deuterons are led through the slit or canal, between the shaded areas, to the lower half of the tube in which they collide, under high potential, with deuterium atoms and molecules to give the observed transmutations to tritium and to helium 3. The gas is constantly circulated between the upper and lower halves of the canal ray tube.



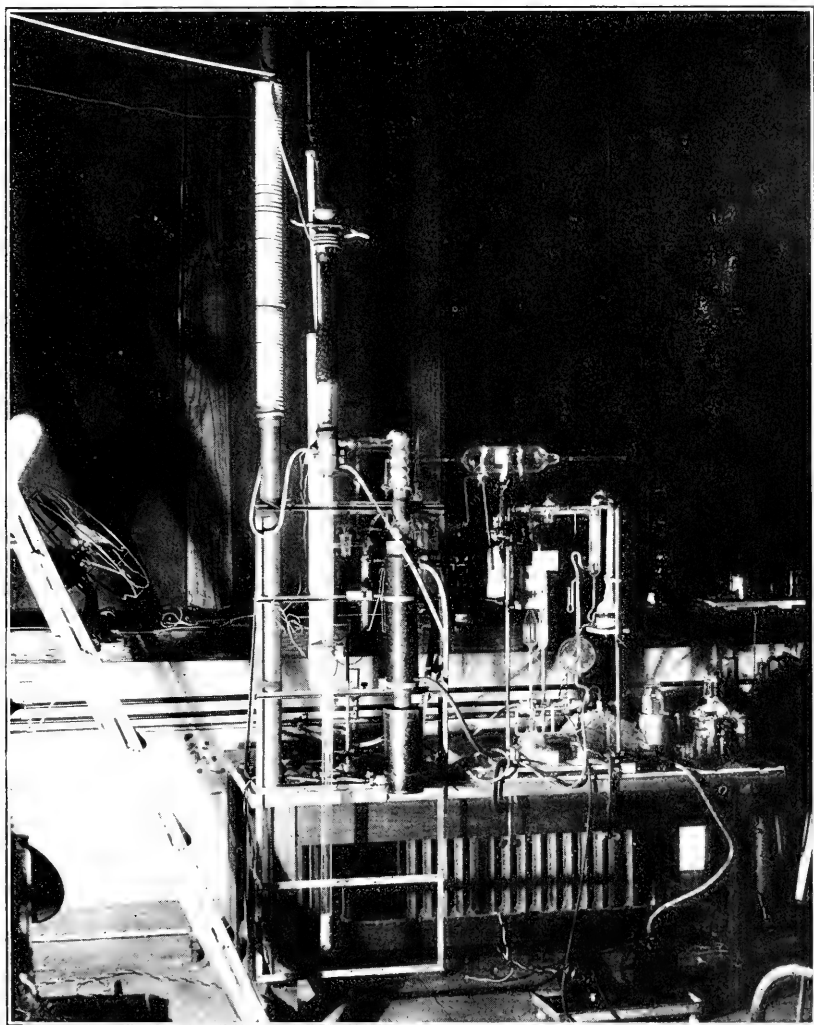
GENERAL VIEW OF ELECTROLYTIC CONCENTRATION OF HEAVY WATER.

Tank A to right contains 160 units for the second stage of the electrolysis. Tank B, shown in detail in plate 2, is a smaller unit, employing recovery of the evolved hydrogen-deuterium mixtures and used for more concentrated solutions. The copper still for distillation of alkaline liquors is shown at C.



ELECTROLYSIS WITH RECOVERY OF HYDROGEN-DEUTERIUM AND OXYGEN BY COMBUSTION AND CONDENSATION.

The hydrogen-deuterium and oxygen are freed from spray in the towers A, containing absorbent cotton, pass through the explosion traps B, and are burned at a pyrex jet C. The water is condensed and collected in D, the enriched residue remaining in the electrolysis vessels water-cooled in tank E.



GENERAL VIEW OF APPARATUS EMPLOYED IN PALMER PHYSICAL LABORATORY, PRINCETON UNIVERSITY, FOR TRANSMUTATION OF DEUTERIUM INTO (A) TRI-
TIUM AND HYDROGEN, (B) HELIUM OF MASS 3 AND NEUTRONS.

The long glass tube shown to the left of the center of the photograph is the actual location of the transmu-
tation process. This unit is shown diagrammatically in figure 2.

SOME CHEMICAL ASPECTS OF LIFE ¹

By Sir FREDERICK GOWLAND HOPKINS, Pres. R. S.

I

The British Association returns to Leicester with assurance of a welcome as warm as that received 26 years ago, and of hospitality as generous. The renewed invitation and the ready acceptance speak of mutual appreciation born of the earlier experience. Hosts and guests have today reasons for mutual congratulations. The Association on its second visit finds Leicester altered in important ways. It comes now to a city duly chartered and the seat of a bishopric. It finds there a center of learning, many fine buildings which did not exist on the occasion of the first visit, and many other evidences of civic enterprise. The citizens of Leicester, on the other hand, will know that since they last entertained it the Association has celebrated its centenary, has four times visited distant parts of the Empire, and has maintained unabated through the years its useful and important activities.

In 1907 the occupant of the Presidential Chair was, as you know, Sir David Gill, the eminent astronomer who, unhappily, like many who listened to his address, is with us no more. Sir David dealt in that address with aspects of science characterized by the use of very exact measurements. The exactitude which he prized and praised has since been developed by modern physics and is now so great that its methods have real esthetic beauty. In contrast, I have to deal with a branch of experimental science which, because it is concerned with living organisms, is in respect of measurement on a different plane. Of the very essence of biological systems is an ineludible complexity, and exact measurement calls for conditions here unattainable. Many may think, indeed, though I am not claiming it here, that in studying life we soon meet with aspects which are nonmetrical. I would have you believe, however, that the data of modern biochemistry which will be the subject of my remarks were won by quantitative methods fully adequate to justify the claims based upon them.

¹ Presidential address before the British Association for the Advancement of Science, Leicester, 1933. Reprinted by permission from the Report of the Association for 1933.

Though speculations concerning the origin of life have given intellectual pleasure to many, all that we yet know about it is that we know nothing. Sir James Jeans once suggested, though not with conviction, that it might be a disease of matter—a disease of its old age! Most biologists, I think, having agreed that life's advent was at once the most improbable and the most significant event in the history of the universe, are content for the present to leave the matter there.

We must recognize, however, that life has one attribute that is fundamental. Whenever and wherever it appears the steady increase of entropy displayed by all the rest of the universe is then and there arrested. There is no good evidence that in any of its manifestations life evades the second law of thermodynamics, but in the downward course of the energy-flow it interposes a barrier and dams up a reservoir which provides potential for its own remarkable activities. The arrest of energy degradation in living nature is indeed a primary biological concept. Related to it, and of equal importance is the concept of organization.

It is almost impossible to avoid thinking and talking of life in this abstract way, but we perceive it, of course, only as manifested in organized material systems, and it is in them we must seek the mechanisms which arrest the fall of energy. Evolution has established division of labor here. From far back the wonderfully efficient functioning of structures containing chlorophyll has, as everyone knows, provided the trap which arrests and transforms radiant energy—fated otherwise to degrade—and so provides power for nearly the whole living world. It is impossible to believe, however, that such a complex mechanism was associated with life's earliest stages. Existing organisms illustrate what was perhaps an earlier method. The so-called "autotrophic" bacteria obtain energy for growth by the catalyzed oxidation of materials belonging wholly to the inorganic world, such as sulphur, iron, or ammonia, and even free hydrogen. These organisms dispense with solar energy, but they have lost in the evolutionary race because their method lacks economy. Other existing organisms, certain purple bacteria, seem to have taken a step toward greater economy, without reaching that of the green cell. They dispense with free oxygen and yet obtain energy from the inorganic world. They control a process in which carbon dioxide is reduced and hydrogen sulphide simultaneously oxidized. The molecules of the former are activated by solar energy which their pigmentary equipment enables these organisms to arrest.

Are we to believe that life still exists in association with systems that are much more simply organized than any bacterial cell? The very minute filter-passing viruses which, owing to their causal rela-

tions with disease, are now the subject of intense study, awaken deep curiosity with respect to this question. We cannot yet claim to know whether or not they are living organisms. In some sense they grow and multiply, but, so far as we yet know with certainty, only when inhabitants of living cells. If they are nevertheless living, this would suggest they they have no independent power of obtaining energy and so cannot represent for us the earliest forms in which life appeared. At present, however, judgment on their biological significance must be suspended. The fullest understanding of all the methods by which energy may be acquired for life's processes is much to be desired.

In any case every living unit is a transformer of energy however acquired, and the science of biochemistry is deeply concerned with these transformations. It is with aspects of that science that I am to deal and if to them I devote much of my address my excuse is that since it became a major branch of inquiry biochemistry has had no exponent in the Chair I am fortunate enough to occupy.

As a progressive scientific discipline it belongs to the present century. From the experimental physiologists of the last century it obtained a charter, and, from a few pioneers of its own, a promise of success; but for the furtherance of its essential aim that century left it but a small inheritance of facts and methods. By its essential or ultimate aim I myself mean an adequate and acceptable description of molecular dynamics in living cells and tissues.

II

When this association began its history in 1831 the first artificial synthesis of a biological product was, as you will remember, but 3 years old. Primitive faith in a boundary between the organic and the inorganic which could never be crossed was only just then realizing that its foundations were gone. Since then, during the century of its existence, the association has seen the pendulum swing back and forth between frank physico-chemical conceptions of life and various modifications of vitalism. It is characteristic of the present position and spirit of science that sounds of the long conflict between mechanists and vitalists are just now seldom heard. It would almost seem, indeed, that tired of fighting in a misty atmosphere each has retired to his tent to await with wisdom the light of further knowledge. Perhaps, however, they are returning to the fight disguised as determinist and indeterminist, respectively. If so the outcome will be of great interest. In any case I feel fortunate in a belief that what I have to say will not, if rightly appraised, raise the old issues. To claim, as I am to claim, that a description of its active chemical

aspects must contribute to any adequate description of life is not to imply that a living organism is no more than a physio-chemical system. It implies that at a definite and recognizable level of its dynamic organization an organism can be logically described in physico-chemical terms alone. At such a level indeed we may hope ultimately to arrive at a description which is complete in itself, just as descriptions at the morphological level of organization may be complete in themselves. There may be yet higher levels calling for discussion in quite different terms.

I wish, however, to remind you of a mode of thought concerning the material basis of life, which though it prevailed when physico-chemical interpretations were fashionable, was yet almost as inhibitory to productive chemical thought and study as any of the claims of vitalism. This was the conception of that material basis as a single entity, as a definite though highly complex chemical compound. Up to the end of the last century and even later the term "protoplasm" suggested such an entity to many minds. In his brilliant presidential address at the association's meeting at Dundee 22 years ago, Sir Edward Sharpey-Schafer, after remarking that the elements composing living substances are few in number, went on to say: "The combination of these elements into a colloid compound represents the physical basis of life, and when the chemist succeeds in building up this compound it will, without doubt, be found to exhibit the phenomena which we are in the habit of associating with the term 'life'." Such a compound would seem to correspond with the "protoplasm" of many biologists, though treated perhaps with too little respect. The presidential claim might have seemed to encourage the biochemist, but the goal suggested would have proved elusive, and the path of endeavor has followed other lines.

So long as the term "protoplasm" retains a morphological significance as in classical cytology, it may be even now convenient enough, though always denoting an abstraction. Insofar, however, as the progress of metabolism with all the vital activities which it supports was ascribed in concrete thought to hypothetical qualities emergent from a protoplasmic complex in its integrity or when substances were held to suffer change only because in each living cell they are first built up, with loss of their own molecular structure and identity, into this complex, which is itself the inscrutable seat of cyclic change, then serious obscurantism was involved.

Had such assumptions been justified the old taunt that when the chemist touches living matter it immediately becomes dead matter would also have been justified. A very distinguished organic chemist, long since dead, said to me in the late eighties: "The chemistry of the living? That is the chemistry of protoplasm; that is super-chemistry; seek, my young friend, for other ambitions."

Research, however, during the present century, much of which has been done since the association last met in Leicester, has yielded knowledge to justify the optimism of the few who started to work in those days. Were there time, I might illustrate this by abundant examples; but I think a single illustration will suffice to demonstrate how progress during recent years has changed the outlook for biochemistry. I will ask you to note the language used 30 years ago to describe the chemical events in active muscle and compare it with that used now. In 1895 Michael Foster, a physiologist of deep vision, dealing with the respiration of tissues, and in particular with the degree to which the activity of muscle depends on its contemporary oxygen supply, expounded the current view which may be thus briefly summarized. The oxygen which enters the muscle from the blood is not involved in immediate oxidations, but is built up into the substance of the muscle. It disappears into some protoplasmic complex on which its presence confers instability. This complex, like all living substance, is to be regarded as incessantly undergoing changes of a double kind, those of building up and those of breaking down. With activity the latter predominates, and in the case of muscle the complex in question explodes, as it were, to yield the energy for contraction. "We cannot yet trace", Foster comments, "the steps taken by the oxygen from the moment it slips from the blood into the muscle substance to the moment when it issues united with carbon as carbonic acid. The whole mystery of life lies hidden in that process, and for the present we must be content with simply knowing the beginning and the end." What we feel entitled to say today concerning the respiration of muscle and of the events associated with its activity requires, as I have suggested, a different language, and for those not interested in technical chemical aspects the very change of language may yet be significant. The conception of continuous building up and continuous breakdown of the muscle substance as a whole, has but a small element of truth. The colloidal muscle structure is, so to speak, an apparatus, relatively stable even as a whole when metabolism is normal, and in essential parts very stable. The chemical reactions which occur in that apparatus have been followed with a completeness which is, I think, striking. It is carbohydrate stores distinct from the apparatus (and in certain circumstances also fat stores) which undergo steady oxidation and are the ultimate sources of energy for muscular work. Essential among successive stages in the chemical breakdown of carbohydrate which necessarily precede oxidation is the intermediate combination of a sugar (a hexose) with phosphoric acid to form an ester. This happening is indispensable for the progress of the next stage, namely the production of lactic acid from the sugar, which is an anaerobic process. The precise happenings to the hexose sugar while in com-

bination with phosphoric acid are from a chemical standpoint remarkable. Very briefly stated they are these. One-half of the sugar molecule is converted into a molecule of glycerin and the other half into one of pyruvic acid. Now with loss of two hydrogen atoms glycerin yields lactic acid, and, with a gain of the same pyruvic acid, also yields lactic acid. The actual happening then is that hydrogen is transferred from the glycerin molecule while still combined with phosphoric acid to the pyruvic acid molecule with the result that two molecules of lactic acid are formed. The lactic acid is then, during a cycle of change which I must not stop to discuss, oxidized to yield the energy required by the muscle.

But the energy from this oxidation is by no means directly available for the mechanical act of contraction. The oxidation occurs indeed after and not before or during a contraction. The energy it liberates secured however the endothermic resynthesis of a substance, creatin phosphate, of which the breakdown at an earlier stage in the sequence of events is the more immediate source of energy for contraction. Even more complicated are these chemical relations, for it would seem that in the transference of energy from its source in the oxidation of carbohydrate to the system which synthesizes creatin phosphate, yet another reaction intervenes, namely, the alternating breakdown and resynthesis of the substance adenylyl pyrophosphate. The sequence of these chemical reactions in muscle has been followed and their relation in time to the phases of contraction and relaxation is established. The means by which energy is transferred from one reacting system to another has till lately been obscure, but current work is throwing light upon this interesting question, and it is just beginning (though only beginning) to show how at the final stage the energy of the reactions is converted into the mechanical response. In parenthesis it may be noted as an illustration of the unity of life that the processes which occur in the living yeast cell in its dealings with sugars are closely similar to those which proceed in living muscle. In the earlier stages they are identical and we now know where they part company. You will, I think, be astonished at the complexity of the events which underlie the activity of a muscle, but you must remember that it is a highly specialized machine. A more direct burning of the fuel could not fit into its complex organization. I am more particularly concerned to feel that my brief summary of the facts will make you realize how much more definite, how much more truly chemical, is our present knowledge than that available when Michael Foster wrote: Ability to recognize the progress of such definite ordered chemical reactions in relation to various aspects of living activity characterizes the current position in biochemistry. I have chosen the case of muscle, and it must serve as my only example, but many such related and

ordered reactions have been studied in other cells and tissues, from bacteria to the brain. Some prove general, some more special. Although we are far indeed from possessing a complete picture in any one case we are beginning in thought to fit not a few pieces together. We are on a line safe for progress.

I must perforce limit the field of my discussion, and in what follows my special theme will be the importance of molecular structure in determining the properties of living systems. I wish you to believe that molecules display in such systems the properties inherent in their structure even as they do in the laboratory of the organic chemist. The theme is no new one, but its development illustrates as well as any other, and to my own mind perhaps better than any other, the progress of biochemistry. Not long ago a prominent biologist, believing in protoplasm as an entity, wrote: "But it seems certain that living protoplasm is not an ordinary chemical compound, and therefore can have no molecular structure in the chemical sense of the word." Such a belief was common. One may remark, moreover, that when the development of colloid chemistry first brought its indispensable aid toward an understanding of the biochemical field, there was a tendency to discuss its bearing in terms of the less specific properties of colloid systems, phase-surfaces, membranes, and the like, without sufficient reference to the specificity which the influence of molecular structure, wherever displayed, impresses on chemical relations and events. In emphasizing its importance I shall leave no time for dealings with the nature of the colloid structures of cells and tissues, all important as they are. I shall continue to deal, though not again in detail, with chemical reactions as they occur within those structures. Only this much must be said. If the colloid structures did not display highly specialized molecular structure at their surface, no reactions would occur; for here catalysis occurs. Were it not equipped with catalysts every living unit would be a static system.

With the phenomena of catalysis I will assume you have general acquaintance. You know that a catalyst is an agent which plays only a temporary part in chemical events which it nevertheless determines and controls. It reappears unaltered when the events are completed. The phenomena of catalysis, though first recognized early in the last century, entered but little into chemical thought or enterprise, till only a few years ago they were shown to have great importance for industry. Yet catalysis is one of the most significant devices of nature, since it has endowed living systems with their fundamental character as transformers of energy, and all evidence suggests that it must have played an indispensable part in the living universe from the earliest stages of evolution.

The catalysts of a living cell are the enzymic structures which display their influences at the surface of colloidal particles or at other surfaces within the cell. Current research continues to add to the great number of these enzymes which can be separated from, or recognized in, living cells and tissues, and to increase our knowledge of their individual functions.

A molecule within the system of the cell may remain in an inactive state and enter into no reactions until at one such surface it comes in contact with an enzymic structure which displays certain adjustments to its own structure. While in such association the inactive molecule becomes (to use a current term) "activated," and then enters on some definite path of change. The one aspect of enzymic catalysis which for the sake of my theme I wish to emphasize is its high specificity. An enzyme is in general adjusted to come into effective relations with one kind of molecule only, or at most with molecules closely related in their structure. Evidence based on kinetics justifies the belief that some sort of chemical combination between enzyme and related molecule precedes the activation of the latter, and for such combinations there must be close correlation in structure. Many will remember that long ago Emil Fischer recognized that enzymic action distinguishes even between two optical isomers and spoke of the necessary relation being as close as that of key and lock.

There is an important consequence of this high specificity in biological catalysis to which I will direct your special attention. A living cell is the seat of a multitude of reactions, and in order that it should retain in a given environment its individual identity as an organism, these reactions must be highly organized. They must be of determined nature and proceed mutually adjusted with respect to velocity, sequence, and in all other relations. They must be in dynamic equilibrium as a whole and must return to it after disturbance. Now if of any group of catalysts, such as are found in the equipment of a cell, each one exerts limited and highly specific influence, this very specificity must be a potent factor in making for organization.

Consider the case of any individual cell in due relations with its environment, whether an internal environment as in the case of the tissue cells of higher animals, or an external environment as in the case of unicellular organisms. Materials for maintenance of the cell enter it from the environment. Discrimination among such materials is primarily determined by permeability relations, but of deeper significance in that selection is the specificity of the cell catalysts. It has often been said that the living cell differs from all nonliving systems in its power of selecting from a hetero-

geneous environment the right material for the maintenance of its structure and activities. It is, however, no vital act but the nature of its specific catalysts which determines what it effectively "selects." If a molecule gains entry into the cell and meets no catalytic influence capable of activating it, nothing further happens save for certain ionic and osmotic adjustments. Any molecule which does meet an adjusted enzyme cannot fail to suffer change and become directed into some one of the paths of metabolism. It must here be remembered, moreover, that enzymes as specific catalysts not only promote reactions, but determine their direction. The glucose molecule, for example, though its inherent chemical potentialities are, of course, always the same, is converted into lactic acid by an enzyme system in muscle but into alcohol and carbon dioxide by another in the yeast cell. It is important to realize that diverse enzymes may act in succession and that specific catalysis has directive as well as selective powers. If it be syntheses in the cell which are most difficult to picture on such lines, we may remember that biological syntheses can be, and are, promoted by enzymes, and there are sufficient facts to justify the belief that a chain of specific enzymes can direct a complex synthesis along lines predetermined by the nature of the enzymes themselves. I should like to develop this aspect of the subject even further, but to do so might tax your patience. I should add that enzyme-control, though so important, is not the sole determinant of chemical organization in a cell. Other aspects of its colloidal structure play their part.

III

It is surely at that level of organization, which is based on the exact coordination of a multitude of chemical events within it, that a living cell displays its peculiar sensitiveness to the influence of molecules of special nature when these enter it from without. The nature of very many organic molecules is such that they may enter a cell and exert no effect. Those proper to metabolism follow, of course, the normal paths of change. Some few, on the other hand, influence the cell in very special ways. When such influence is highly specific in kind, it means that some element of structure in the entrant molecule is adjusted to meet an aspect of molecular structure somewhere in the cell itself. We can easily understand that in a system so minute the intrusion even of a few such molecules may so modify existing equilibria as to affect profoundly the observed behavior of the cell.

Such relations, though by no means confined to them, reach their greatest significance in the higher organisms, in which individual tissues, chemically diverse, differentiated in function and separated in space, so react upon one another through chemical agencies trans-

mitted through the circulation as to coordinate by chemical transport the activities of the body as a whole. Unification by chemical means must today be recognized as a fundamental aspect of all such organisms. In all of them it is true that the nervous system has pride of place as the highest seat of organizing influence, but we know today that even this influence is often, if not always, exerted through properties inherent in chemical molecules. It is indeed most significant for my general theme to realize that when a nerve impulse reaches a tissue the sudden production of a definite chemical substance at the nerve ending may be essential to the response of that tissue to the impulse. It is a familiar circumstance that when an impulse passes to the heart by way of the vagus nerve fibers the beat is slowed, or, by a stronger beat, arrested. That is, of course, part of the normal control of the heart's action. Now it has been shown that whenever the heart receives vagus impulses the substance acetylcholine is liberated within the organ. To this fact is added the further fact that, in the absence of the vagus influence, the artificial injection of minute graded doses of acetylcholine so acts upon the heart as to reproduce in every detail the effects of graded stimulation of the nerve. Moreover, evidence is accumulating to show that in the case of other nerves belonging to the same morphological group as the vagus, but supplying other tissues, this same liberation of acetylcholine accompanies activity, and the chemical action of this substance upon such tissues again produces effects identical with those observed when the nerves are stimulated. More may be claimed. The functions of another group of nerves are opposed to those of the vagus group; impulses, for instance, through certain fibers accelerate the heart beat. Again a chemical substance is liberated at the endings of such nerves, and this substance has itself the property of accelerating the heart. We find then that such organs and tissues respond only indirectly to whatever nonspecific physical change may reach the nerve ending. Their direct response is to the influence of particular molecules with an essential structure when these intrude into their chemical machinery.

It follows that the effect of a given nerve stimulus may not be confined to the tissue which it first reaches. There may be humeral transmissions of its effect, because the liberated substance enters the lymph and blood. This again may assist the coordination of events in the tissues.

From substances produced temporarily and locally and by virtue of their chemical properties translating for the tissues the messages of nerves, we may pass logically to consideration of those active substances which carry chemical messages from organ to organ. Such in the animal body are produced continuously in specialized organs,

and each has its special seat or seats of action where it finds chemical structures adjusted in some sense or other to its own.

I shall be here on familiar ground, for that such agencies exist, and bear the name of hormones, is common knowledge. I propose only to indicate how many and diverse are their functions as revealed by recent research, emphasizing the fact that each one is a definite and relatively simple substance with properties that are primarily chemical and in a derivative sense physiological. Our clear recognition of this, based at first on a couple of instances, began with this century, but our knowledge of their number and nature is still growing rapidly today.

We have long known, of course, how essential and profound is the influence of the thyroid gland in maintaining harmonious growth in the body, and in controlling the rate of its metabolism. Three years ago a brilliant investigation revealed the exact molecular structure of the substance—thyroxin—which is directly responsible for these effects. It is a substance of no great complexity. The constitution of adrenalin has been longer known and likewise its remarkable influence in maintaining a number of important physiological adjustments. Yet it is again a relatively simple substance. I will merely remind you of secretin, the first of these substances to receive the name of hormone, and of insulin, now so familiar because of its importance in the metabolism of carbohydrates and its consequent value in the treatment of diabetes. The most recent growth of knowledge in this field has dealt with hormones which, in most remarkable relations, coordinate the phenomena of sex.

It is the circulation of definite chemical substances produced locally that determines during the growth of the individual, the proper development of all secondary sexual characters. The properties of other substances secure the due process of individual development from the unfertilized ovum to the end of fetal life. When an ovum ripens and is discharged from the ovary a substance, now known as œstrin, is produced in the ovary itself, and so functions as to bring about all those changes in the female body which make secure the fertilization of the ovum. On the discharge of the ovum new tissue, constituting the so-called corpus luteum, arises in its place. This then produces a special hormone which in its turn evokes all those changes in tissues and organs that secure a right destiny for the ovum after it has been fertilized. It is clear that these two hormones do not arise simultaneously, for they must act in alternation, and it becomes of great interest to know how such succession is secured. The facts here are among the most striking. Just as higher nerve centers in the brain control and coordinate the activities of lower centers, so it would seem do hormones, functioning at, so to speak, a higher level in organization, coordinate the activities of other hormones. It is a substance

produced in the anterior portion of the pituitary gland situated at the base of the brain, which by circulating to the ovary controls the succession of its hormonal activities. The cases I have mentioned are far from exhausting the numerous hormonal influences now recognized.

For full appreciation of the extent to which chemical substances control and coordinate events in the animal body by virtue of their specific molecular structure, it is well not to separate too widely in thought the functions of hormones from those of vitamins. Together they form a large group of substances of which every one exerts upon physiological events its own indispensable chemical influence.

Hormones are produced in the body itself, while vitamins must be supplied in the diet. Such a distinction is, in general, justified. We meet occasionally, however, an animal species able to dispense with an external supply of this or that vitamin. Evidence shows, however, that individuals of that species, unlike most animals, can in the course of their metabolism synthesize for themselves the vitamin in question. The vitamin then becomes a hormone. In practice the distinction may be of great importance, but for an understanding of metabolism the functions of these substances are of more significance than their origin.

The present activity of research in the field of vitamins is prodigious. The output of published papers dealing with original investigations in the field has reached nearly a thousand in a single year. Each of the vitamins at present known is receiving the attention of numerous observers in respect both of its chemical and biological properties, and though many publications deal, of course, with matters of detail, the accumulation of significant facts is growing fast.

It is clear that I can cover but little ground in any reference to this wide field of knowledge. Some aspects of its development have been interesting enough. The familiar circumstance that attention was drawn to the existence of one vitamin (B_1 so called) because populations in the East took to eating milled rice instead of the whole grain; the gradual growth of evidence which links the physiological activities of another vitamin (D) with the influence of solar radiation of the body, and has shown that they are thus related, because rays of definite wave length convert an inactive precursor into the active vitamin, alike when acting on foodstuffs or on the surface of the living body; the fact again that the recent isolation of vitamin C, and the accumulation of evidence for its nature started from the observation that the cortex of the adrenal gland displayed strongly reducing properties; or yet again the proof that a yellow pigment widely distributed among plants, while not

the vitamin itself, can be converted within the body into vitamin A; these and other aspects of vitamin studies will stand out as interesting chapters in the story of scientific investigation.

In this very brief discussion of hormones and vitamins I have so far referred only to their functions as manifested in the animal body. Kindred substances, exerting analogous functions, are, however, of wide and perhaps of quite general biological importance. It is certain that many micro-organisms require a supply of vitaminlike substances for the promotion of growth, and recent research of a very interesting kind has demonstrated in the higher plants the existence of specific substances produced in special cells which stimulate growth in other cells, and so in the plant as a whole. These so-called auxines are essentially hormones. Section B will soon be listening to an account of their chemical nature.

It is of particular importance to my present theme and a source of much satisfaction to know that our knowledge of the actual molecular structure of hormones and vitamins is growing fast. We have already exact knowledge of the kind in respect to not a few. We are indeed justified in believing that within a few years such knowledge will be extensive enough to allow a wide view of the correlation between molecular structure and physiological activity. Such correlation has long been sought in the case of drugs, and some generalizations have been demonstrated. It should be remembered, however, that until quite lately only the structure of the drug could be considered. With increasing knowledge of the tissue structures pharmacological actions will become much clearer.

I cannot refrain from mentioning here a set of relations connected especially with the phenomena of tissue growth which are of particular interest. It will be convenient to introduce some technical chemical considerations in describing them, though I think the relations may be clear without emphasis being placed on such details. The vitamin, which in current usage is labeled "A", is essential for the general growth of an animal. Recent research has provided much information as to its chemical nature. Its molecule is built up of units which possess what is known to chemists as the "isoprene structure." These are condensed in a long carbon chain which is attached to a ring structure of a specific kind. Such a constitution relates it to other biological compounds, in particular to certain vegetable pigments, one of which a carotene, so called, is the substance which I have mentioned as being convertible into the vitamin. For the display of an influence upon growth, however, the exact details of the vitamin's proper structure must be established. Now turning to vitamin D, of which the activity is more specialized, controlling as it does the growth of bone in particular, we have learned that the unit elements in its structure are again isoprene radicals; but instead of forming

a long chain as in vitamin A they are united into a system of condensed rings. Similar rings form the basal component of the molecules of sterols, substances which are normal constituents of nearly every living cell. It is one of these, inactive itself, which ultra-violet radiation converts into vitamin D. We know that as stated each of these vitamins stimulates growth in tissue cells. Next consider another case of growth stimulation, different because pathological in nature. As you are doubtless aware, it is well known that long contact with tar induces a cancerous growth of the skin. Very important researches have recently shown that particular constituents in the tar are alone concerned in producing this effect. It is being further demonstrated that the power to produce cancer is associated with a special type of molecular structure in these constituents. This structure, like that of the sterols, is one of condensed rings, the essential difference being that (in chemical language) the sterol rings are hydrogenated, whereas those in the cancer-producing molecules are not. Hydrogenation indeed destroys the activity of the latter. Recall, however, the ovarian hormone oestrin. Now the molecular structure of oestrin has the essential ring structure of a sterol, but one of the constituent rings is not hydrogenated. In a sense therefore the chemical nature of oestrin links vitamin D with that of cancer-producing substances. Further, it is found that substances with pronounced cancer-producing powers may produce effects in the body like those of oestrin. It is difficult when faced with such relations not to wonder whether the metabolism of sterols, which when normal can produce a substance stimulating physiological growth, may in very special circumstances be so perverted as to produce within living cells a substance stimulating pathological growth. Such a suggestion must, however, with present knowledge, be very cautiously received. It is wholly without experimental proof. My chief purpose in this reference to this very interesting set of relations is to emphasize once more the significance of chemical structure in the field of biological events.

Only the end results of the profound influence which minute amounts of substances with adjusted structure exert upon living cells or tissues can be observed in the intact bodies of man or animals. It is doubtless because of the elaborate and sensitive organization of chemical events in every tissue cell that the effects are proportionally so great.

It is an immediate task of biochemistry to explore the mechanism of such activities. It must learn to describe in objective chemical terms precisely how and where such molecules as those of hormones and vitamins intrude into the chemical events of metabolism. It is indeed now beginning this task which is by no means outside the scope of its methods. Efforts of this and of similar kind cannot

fail to be associated with a steady increase in knowledge of the whole field of chemical organization in living organisms, and to this increase we look forward with confidence. The promise is there. Present methods can still go far, but I am convinced that progress of the kind is about to gain great impetus from the application of those new methods of research which chemistry is inheriting from physics: X-ray analysis; the current studies of unimolecular surface films and of chemical reactions at surfaces; modern spectroscopy; the quantitative developments of photochemistry; no branch of inquiry stands to gain more from such advances in technique than does biochemistry at its present stage. Especially is this true in the case of the colloidal structure of living systems, of which in this address I have said so little.

IV

As an experimental science, biochemistry, like classical physiology and much of experimental biology, has obtained, and must continue to obtain, many of its data from studying parts of the organism in isolation, but parts in which dynamic events continue. Though fortunately it has also methods of studying reactions as they occur in intact living cells, intact tissues, and, of course, in the intact animal, it is still entitled to claim that its studies of parts are consistently developing its grasp of the wholes it desires to describe, however remote that grasp may be from finality. Justification for any such claim has been challenged in advance from a certain philosophic standpoint. Not from that of General Smuts, though in his powerful address which signalized our centenary meeting, he, like many philosophers today, emphasized the importance of properties which emerge from systems in their integrity, bidding us remember that a part while in the whole is not the same as the part in isolation. He hastened to admit in a subsequent speech, however, that for experimental biology, as for any other branch of science, it was logical and necessary to approach the whole through its parts. Nor again is the claim challenged from the standpoint of such a teacher as A. N. Whitehead, though in his philosophy of organic mechanism there is no real entity of any kind without internal and multiple relations, and each whole is more than the sum of its parts. I nevertheless find *ad hoc* statements in his writings which directly encourage the methods of biochemistry. In the teachings of J. S. Haldane, however, the value of such methods have long been directly challenged. Some here will perhaps remember that in his address to section I 25 years ago he described a philosophic standpoint which he has courageously maintained in many writings since. Dr. Haldane holds that to the enlightened biologist a living organism does not present a problem for analysis; it is, *qua* organism, axiomatic. Its essential attributes are

axiomatic; heredity, for example, is for biology not a problem but an axiom. "The problem of physiology is not to obtain piecemeal physico-explanations of physiological processes" (I quote from the 1885 address), "but to discover by observation and experiment the relatedness to one another of all the details of structure and activity in each organism as expressions of its nature as one organism." I cannot pretend adequately to discuss these views here. They have often been discussed by others, not always perhaps with understanding. What is true in them is subtle, and I doubt if their author has ever found the right words in which to bring to most others a conviction of such truth. It is involved in a world outlook. What I think is scientifically faulty in Haldane's teaching is the a priori element which leads to bias in the face of evidence. The task he sets for the physiologist seems vague to most people, and he forgets that with good judgment a study of parts may lead to an intellectual synthesis of value. In 1885 he wrote: "That a meeting point between biology and physical science may at at some time be found there is no reason for doubting. But we may confidently predict that if that meeting point is found, and one of the two sciences is swallowed up, that one will not be biology." He now claims, indeed, that biology has accomplished the heavy meal because physics has been compelled to deal no longer with Newtonian entities but, like the biologist, with organisms such as the atom proves to be. Is it not, then, enough for my present purpose to remark on the significance of the fact that not until certain atoms were found spontaneously splitting piecemeal into parts, and others were afterward so split in the laboratory, did we really know anything about the atom as a whole?

At this point, however, I will ask you not to suspect me of claiming that all the attributes of living systems or even the more obvious among them are necessarily based upon chemical organization alone. I have already expressed my own belief that this organization will account for one striking characteristic of every living cell—its ability, namely, to maintain a dynamic individuality in diverse environments. Living cells display other attributes even more characteristic of themselves; they grow, multiply, inherit qualities and transmit them. Although to distinguish levels of organization in such systems may be to abstract from reality it is not illogical to believe that such attributes as these are based upon organization at a level which is in some sense higher than the chemical level. The main necessity from the standpoint of biochemistry is then to decide whether nevertheless at its own level, which is certainly definable, the results of experimental studies are self-contained and consistent.

This is assuredly true of the data which biochemistry is now acquiring. Never during its progress has chemical consistency shown itself to be disturbed by influences of any ultrachemical kind.

Moreover, before we assume that there is a level of organization at which chemical controlling agencies must necessarily cease to function, we should respect the intellectual parsimony taught by Occam and be sure of their limitations before we seek for superchemical entities as organizers. There is no orderly succession of events which would seem less likely to be controlled by the mere chemical properties of a substance than the cell divisions and cell differentiation which intervene between the fertilized ovum and the finished embryo. Yet it would seem that a transmitted substance, a hormone in essence, may play an unmistakable part in that remarkable drama. It has for some years been known that, at an early stage of development, a group of cells forming the so-called "organizer" of Spemann induces the subsequent stages of differentiation in other cells. The latest researches seem to show that a cell-free extract of this "organizer" may function in its place. The substance concerned is, it would seem, not confined to the "organizer" itself, but is widely distributed outside, though not in, the embryo. It presents, nevertheless, a truly remarkable instance of chemical influence.

It would be out of place in such a discourse as this to attempt any discussion of the psychophysical problem. However much we may learn about the material systems which, in their integrity, are associated with consciousness, the nature of that association may yet remain a problem. The interest of that problem is insistent and it must be often in our thoughts. Its existence, however, justifies no prejudgments as to the value of any knowledge of a consistent sort which the material systems may yield to experiment.

V

It has become clear, I think, that chemical modes of thought, whatever their limitation, are fated profoundly to affect biological thought. If, however, the biochemist should at any time be inclined to overrate the value of his contributions to biology, or to under-rate the magnitude of problems outside his province, he will do well sometimes to leave the laboratory for the field, or to seek even in the museum a reminder of that infinity of adaptations of which life is capable. He will then not fail to work with a humble mind, however great his faith in the importance of the methods which are his own.

It is surely right, however, to claim that in passing from its earlier concern with dead biological products to its present concern

with active processes within living organisms, biochemistry has become a true branch of progressive biology. It has opened up modes of thought about the physical basis of life which could scarcely be employed at all a generation ago. Such data and such modes of thought as it is now providing are pervasive, and must appear as aspects in all biological thought. Yet these aspects are, of course, only partial. Biology in all its aspects is showing rapid progress, and its bearing on human welfare is more and more evident.

Unfortunately, the nature of this new biological progress and its true significance is known to but a small section of the lay public. Few will doubt that popular interest in science is extending, but it is mainly confined to the more romantic aspects of modern astronomy and physics. That biological advances have made less impression is probably due to more than one circumstance, of which the chief, doubtless, is the neglect of biology in our educational system. The startling data of modern astronomy and physics, though of course only when presented in their most superficial aspects, find an easier approach to the uninformed mind than those of the new experimental biology can hope for. The primary concepts involved are paradoxically less familiar. Modern physical science, moreover, has been interpreted to the intelligent public by writers so brilliant that their books have had a great and stimulating influence.

Lord Russell once ventured on the statement that in passing from physics to biology one is conscious of a transition from the cosmic to the parochial, because from a cosmic point of view life is a very unimportant affair. Those who know that supposed parish well are convinced that it is rather a metropolis entitled to much more attention than it sometimes obtains from authors of guide-books to the universe. It may be small in extent, but is the seat of all the most significant events. In too many current publications, purporting to summarize scientific progress, biology is left out or receives but scant reference. Brilliant expositions of all that may be met in the region where modern science touches philosophy have directed thought straight from the implications of modern physics to the nature and structure of the human mind, and even to speculation concerning the mind of the Deity. Yet there are aspects of biological truth already known which are certainly germane to such discussions, and probably necessary for their adequacy.

VI

It is, however, because of its extreme importance to social progress that public ignorance of biology is especially to be regretted. Sir Henry Dale has remarked that "it is worth while to consider today whether the imposing achievements of physical science have

not already, in the thought and interests of men at large, as well as in technical and industrial development, overshadowed in our educational and public policy those of biology to an extent which threatens a one-sided development of science itself and of the civilization which we hope to see based on science." Sir Walter Fletcher, whose death during the past year has deprived the nation of an enlightened adviser, almost startled the public, I think, when he said in a national broadcast that "we can find safety and progress only in proportion as we bring into our methods of statecraft the guidance of biological truth." That statecraft, in its dignity, should be concerned with biological teaching, was a new idea to many listeners. A few years ago the Cambridge philosopher, Dr. C. D. Broad, who is much better acquainted with scientific data than are many philosophers, remarked upon the misfortune involved in the unequal development of science; the high degree of our control over inorganic nature combined with relative ignorance of biology and psychology. At the close of a discussion as to the possibility of continued mental progress in the world, he summed up by saying that the possibility depends on our getting an adequate knowledge and control of life and mind before the combination of ignorance on these subjects with knowledge of physics and chemistry wrecks the whole social system. He closed with the somewhat startling words: "Which of the runners in this very interesting race will win it is impossible to foretell. But physics and death have a long start over psychology and life!" No one surely will wish for, or expect, a slowing in the pace of the first, but the quickening up in the latter which the last few decades have seen is a matter for high satisfaction. But, to repeat, the need for recognizing biological truth as a necessary guide to individual conduct and no less to statecraft and social policy still needs emphasis today. With frank acceptance of the truth that his own nature is congruent with all those aspects of nature at large which biology studies, combined with intelligent understanding of its teaching, man would escape from innumerable inhibitions due to past history and present ignorance, and equip himself for higher levels of endeavor and success.

Inadequate as at first sight it may seem when standing alone in support of so large a thesis, I must here be content to refer briefly to a single example of biological studies bearing upon human welfare. I will choose one which stands near to the general theme of my address. I mean the current studies of human and animal nutrition. You are well aware that during the last 20 years—that is, since it adopted the method of controlled experiment—the study of nutrition has shown that the needs of the body are much more complex than was earlier thought, and in particular that substances

consumed in almost infinitesimal amounts may, each in its way, be as essential as those which form the bulk of any adequate dietary. This complexity in its demands will, after all, not surprise those who have in mind the complexity of events in the diverse living tissues of the body.

My earlier reference to vitamins, which had somewhat different bearings, was, I am sure, not necessary for a reminder of their nutritional importance. Owing to abundance of all kinds of advertisement vitamins are discussed in the drawing room as well as in the dining room, and also, though not so much, in the nursery, while at present perhaps not enough in the kitchen. Unfortunately, among the uninformed their importance in nutrition is not always viewed with discrimination. Some seem to think nowadays that if the vitamin supply is secured the rest of the dietary may be left to chance, while others suppose that they are things so good that we cannot have too much of them. Needless to say, neither assumption is true. With regard to the second indeed it is desirable, now that vitamin concentrates are on the market and much advertised, to remember that excess of a vitamin may be harmful. In the case of that labeled D at least we have definite evidence of this. Nevertheless, the claim that every known vitamin has highly important nutritional functions is supported by evidence which continues to grow. It is probable, but perhaps not yet certain, that the human body requires all that are known.

The importance of detail is no less in evidence when the demands of the body for a right mineral supply are considered. A proper balance among the salts which are consumed in quantity is here of prime importance, but that certain elements which ordinary foods contain in minute amounts are indispensable in such amounts is becoming sure. To take but a single instance: the necessity of a trace of copper, which exercises somewhere in the body an indispensable catalytic influence on metabolism, is as essential in its way as much larger supplies of calcium, magnesium, potassium, or iron. Those in close touch with experimental studies continually receive hints that factors still unknown contribute to normal nutrition, and those who deal with human dietaries from a scientific standpoint know that an ideal diet cannot yet be defined. This reference to nutritional studies is indeed mainly meant to assure you that the great attention they are receiving is fully justified. No one here, I think, will be impressed with the argument that because the human race has survived till now in complete ignorance of all such details the knowledge being won must have academic interest alone. This line of argument is very old and never right.

One thing I am sure may be claimed for the growing enlightenment concerning human nutrition and the recent recognition of its

study. It has already produced one line of evidence to show that nurture can assist nature to an extent not freely admitted a few years ago. That is a subject which I wish I could pursue. I cannot myself doubt that various lines of evidence, all of which should be profoundly welcome, are pointing in the same direction.

Allow me just one final reference to another field of nutritional studies. Their great economic importance in animal husbandry calls for full recognition. Just now agricultural authorities are becoming acutely aware of the call for a better control of the diseases of animals. Together these involve an immense economic loss to the farmers, and therefore to the country. Although, doubtless, its influence should not be exaggerated, faulty nutrition plays no small share in accounting for the incidence of some among these diseases, as researches carried out at the Rowett Institute in Aberdeen and elsewhere are demonstrating. There is much more of such work to be done with great profit.

VII

In every branch of science the activity of research has greatly increased during recent years. This all will have realized, but only those who are able to survey the situation closely can estimate the extent of that increase. It occurred to me at one time that an appraisalment of research activities in this country, and especially the organization of State-aided research, might fittingly form a part of my address. The desire to illustrate the progress of my own subject led me away from that project. I gave some time to a survey, however, and came to the conclusion, among others, that from 8 to 10 individuals in the world are now engaged upon scientific investigations for every one so engaged 20 years ago. It must be remembered, of course, that not only has research endowment greatly increased in America and Europe, but that Japan, China, and India have entered the field and are making contributions to science of real importance. It is sure that, whatever the consequences, the increase of scientific knowledge is at this time undergoing a positive acceleration.

Apropos, I find difficulty as today's occupant of this important scientific pulpit in avoiding some reference to impressive words spoken by my predecessor which are still echoed in thought, talk, and print. In his wise and eloquent address at York, Sir Alfred Ewing reminded us with serious emphasis that the command of Nature has been put into man's hand before he knows how to command himself. Of the dangers involved in that indictment he warned us; and we should remember that General Smuts also sounded the same note of warning in London.

Of science itself it is, of course, no indictment. It may be thought of rather as a warning signal to be placed on her road: "Dangerous

hill ahead", perhaps, or "Turn right"; not, however, "Go slow", for that advice science cannot follow. The indictment is of mankind. Recognition of the truth it contains cannot be absent from the minds of those whose labors are daily increasing mankind's command of Nature; but it is due to them that the truth should be viewed in proper perspective. It is, after all, war, to which science has added terrors, and the fear of war, which alone give it real urgency; an urgency which must, of course, be felt in these days when some nations at least are showing the spirit of selfish and dangerous nationalism. I may be wrong, but it seems to me that, war apart, the gifts of science and invention have done little to increase opportunities for the display of the more serious of man's irrational impulses. The worst they do, perhaps, is to give to clever and predatory souls that keep within the law the whole world for their depredations, instead of a parish or a country as of yore.

But Sir Alfred Ewing told us of "the disillusion with which, now standing aside, he watches the sweeping pageant of discovery and invention in which he used to make unbounded delight." I wish that one to whom applied science and this country owe so much might have been spared such disillusion, for I suspect it gives him pain. I wonder whether, if he could have added to an "engineer's outlook" the outlook of a biologist, the disillusion would still be there. As one just now advocating the claims of biology, I would much like to know. It is sure, however, that the gifts of the engineer to humanity at large are immense enough to outweigh the assistance he may have given to the forces of destruction.

It may be claimed for biological science, in spite of vague references to bacterial warfare and the like, that it is not of its nature to aid destruction. What it may do toward making man as a whole more worthy of his inheritance has yet to be fully recognized. On this point I have said much. Of its service to his physical betterment you will have no doubts. I have made but the bare reference in this address to the support that biological research gives to the art of medicine. I had thought to say much more of this, but found that if I said enough I could say nothing else.

There are two other great questions so much to the front just now that they tempt a final reference. I mean, of course, the paradox of poverty amidst plenty and the replacement of human labor by machinery. Applied science should take no blame for the former, but indeed claim credit unfairly lost. It is not within my capacity to say anything of value about the paradox and its cure; but I confess that I see more present danger in the case of "Money versus Man" than danger present or future in that of the "Machine versus Man"!

With regard to the latter it is surely right that those in touch with science should insist that the replacement of human labor will con-

tinue. Those who doubt this cannot realize the meaning of that positive acceleration in science, pure and applied, which now continues. No one can say what kind of equilibrium the distribution of leisure is fated to reach. In any case an optimistic view as to the probable effects of its increase may be justified.

It need not involve a revolutionary change if there is real planning for the future. Lord Melchett was surely right when some time ago he urged on the upper House that present thought should be given to that future; but I think few men of affairs seriously believe what is yet probable, that the replacement we are thinking of will impose a new structure upon society. This may well differ in some essentials from any of those alternative social forms of which the very names now raise antagonisms. I confess that if civilization escapes its other perils I should fear little the final reign of the machine. We should not altogether forget the difference in use which can be made of real and ample leisure compared with that possible for very brief leisure associated with fatigue; nor the difference between compulsory toil and spontaneous work. We have to picture, moreover, the reactions of a community which, save for a minority, has shown itself during recent years to be educable. I do not think it fanciful to believe that our highly efficient national broadcasting service, with the increased opportunities which the coming of short wave length transmission may provide, might well take charge of the systematic education of adolescents after the personal influence of the schoolmaster has prepared them to profit by it. It would not be a technical education but an education for leisure. Listening to organized courses of instruction might at first be for the few; but ultimately might become habitual in the community which it would specifically benefit.

In parenthesis allow me a brief further reference to "planning." The word is much to the front just now, chiefly in relation with current enterprises. But there may be planning for more fundamental developments; for future adjustment to social reconstructions. In such planning the trained scientific mind must play its part. Its vision of the future may be very limited, but in respect of material progress and its probable consequences science (I include all branches of knowledge to which the name applies) has at least better data for prophecy than other forms of knowledge.

It was long ago written, "Wisdom and knowledge shall be stability of Thy times." Though statesmen may have wisdom adequate for the immediate and urgent problems with which it is their fate to deal, there should yet be a reservoir of synthesized and clarified knowledge on which they can draw. The technique which brings governments in contact with scientific knowledge in particular, though greatly improved of late, is still imperfect. In any case the politician is perforce concerned with the present rather than the future. I

have recently read Bacon's New Atlantis afresh and have been thinking about his Solomon's House. We know that the rules for the functioning of that House were mistaken because the philosopher drew them up when in the mood of a Lord Chancellor; but insofar as the philosopher visualized therein an organization of the best intellects bent on gathering knowledge for future practical services, his idea was a great one. When civilization is in danger and society in transition might there not be a House recruited from the best intellects in the country with functions similar (*mutatis mutandis*) to those of Bacon's fancy? A House devoid of politics, concerned rather with synthesizing existing knowledge, with a sustained appraisalment of the progress of knowledge, and continuous concern with its bearing upon social readjustments. It is not to be pictured as composed of scientific authorities alone. It would be rather an intellectual exchange where thought would go ahead of immediate problems. I believe, perhaps foolishly, that given time I might convince you that the functions of such a House, in such days as ours, might well be real. Here I must leave them to your fancy, well aware that in the minds of many I may by this bare suggestion lose all reputation as a realist!

I will now hasten to my final words. Most of us have had a tendency in the past to fear the gift of leisure to the majority. To believe that it may be a great social benefit requires some mental adjustment, and a belief in the educability of the average man or woman.

But if the political aspirations of the nations should grow sane, and the artificial economic problems of the world be solved, the combined and assured gifts of health, plenty, and leisure may prove to be the final justification of applied science. In a community advantaged by these each individual will be free to develop his own innate powers, and, becoming more of an individual, will be less moved by those herd instincts which are always the major danger to the world.

You may feel that throughout this address I have dwelt exclusively on the material benefits of science to the neglect of its cultural value. I would like to correct this in a single closing sentence. I believe that for those who cultivate it in a right and humble spirit, science is one of the humanities; no less.

COMMERCIAL EXTRACTION OF BROMINE FROM SEA WATER¹

By LEROY C. STEWART

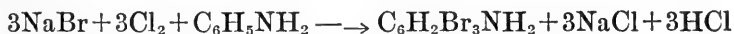
The Dow Chemical Company, Midland, Mich.

[With 7 plates]

In 1924 the production of free and chemically combined bromine in this country amounted to approximately 2 million pounds. In 1931 this quantity had risen to about 9 million pounds, all of which was being produced from natural brines and from bitterns resulting from evaporation of sea water. This remarkable increase in consumption of bromine was due largely to the use of ethylene dibromide in conjunction with tetraethyllead in the treatment of gasoline motor fuel.

A number of years ago it became evident that the demand for bromine was becoming so great that its ordinary sources were inadequate and that new ones would have to be employed. It was logical that sea water should be considered for this purpose, in spite of the fact that its bromine content is less than 70 parts per million, since the enormous quantities of it which are available would insure an inexhaustible source of raw material. It was up to the chemist and engineer, however, to develop a practical and economical method of extracting this desirable halogen element.

The Ethyl Gasoline Corporation was one of the pioneers along this line. In 1924 they operated a small-scale plant with sea water as its source of bromine and produced tribromoaniline which can be used with tetraethyllead in the treatment of gasoline. Some months later, the same organization operated the process on board a boat, the *S. S. Ethyl (4)*.² Their method involved the addition of aniline to chlorinated sea water to form tribromoaniline according to the reaction:



A number of years ago the Dow Chemical Company likewise undertook the problem of extracting bromine from sea water, but

¹ Reprinted by permission from *Industrial and Engineering Chemistry*, vol. 26, p. 361, April 1934.

² Numbers in parentheses refer to list of literature cited at end of paper.

proposed to obtain it in the pure, elemental state by a process somewhat similar to that in use on natural brines at their plant in Midland, Mich. It was recognized that modifications and refinements would have to be made in the old procedure, but the basic principle was considered practical and economically sound. This process consists essentially of (a) oxidizing a natural bromide-containing brine with chlorine to liberate the bromine, (b) blowing the free bromine out of solution with air, and (c) absorbing the bromine from the air with an alkali carbonate solution from which it subsequently can be recovered in a commercially desirable form.

Through many years of experience and effort, the Dow process has been developed to the point where it is possible to recover, consistently, 95 percent of the bromine content of the natural brines. The latter contain approximately 25 percent total solids, consisting chiefly of the chlorides of sodium, calcium, and magnesium, together with approximately 1,300 p. p. m. bromine. Sea water, however, contains about 3.5 percent total solids, and only 65 to 70 p. p. m. bromine. This is approximately the same bromine content as that of the waste effluent from the commercial process just mentioned. Consequently, when laboratory work was started on the problem of removing bromine from sea water, it is not surprising that at first a low efficiency was obtained.

RESEARCH LABORATORY DEVELOPMENTS

It was realized that an addition of acid as well as chlorine would be necessary in order to obtain a satisfactory yield of bromine from sea water on account of its alkalinity, as indicated by its pH of 7.2.

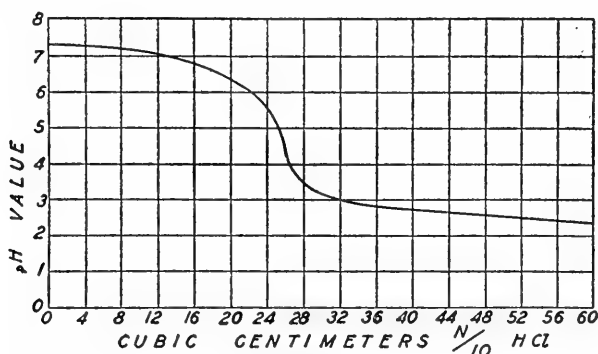


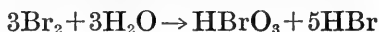
FIG. 1

EFFECT OF ADDITION OF ACID ON pH OF SEA WATER

Otherwise, when the solution was chlorinated, neutralization would have been effected at the expense of the liberated bromine. At the same time there would have been a corresponding formation of

oxidized bromine products from which bromine could not have been liberated easily again by chlorine.

However, it was found that even in carefully neutralized sea water, a satisfactory yield of bromine was not obtained. An explanation of this appeared to be that in the exceptionally dilute solution the liberated bromine hydrolyzed to form bromic and hydrobromic acids according to the equation:



This being the case, such reaction would have continued until a sufficient concentration of hydrogen ions was obtained to suppress the hydrolysis.

In the production of bromine from Michigan brines, some hydrolysis and reabsorption of the halogen, with the attendant formation of acid, had been encountered. Because of the comparatively smaller volume handled in the case of the natural brine, it was

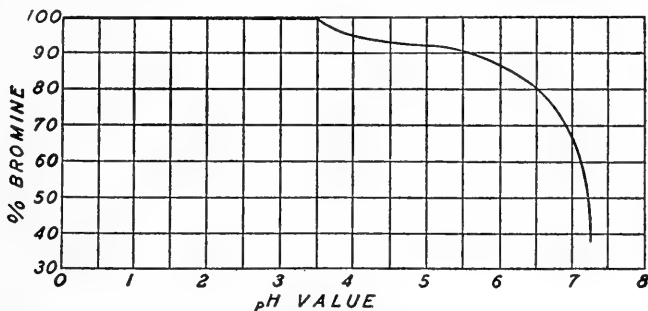


FIG. 2

EFFECT OF pH ON PERCENTAGE OF BROMINE LIBERATED
IN SEA WATER

feasible to permit such acidification by hydrolysis to take place and still to make a satisfactory recovery of the bromine. However, in the case of the enormous quantity of liquid involved with sea water as the source of bromine, such acidification by hydrolysis would be uneconomical. Careful laboratory research, involving potentiometric titration of natural sea water, showed that reabsorption of free bromine by hydrolysis ceased if the hydrogen-ion concentration were increased to a pH of 3 or 4 by the addition of acid from an outside source. This indicated, therefore, that in order to liberate bromine in sea water completely and efficiently, it would be necessary first to add sufficient acid to give a pH of approximately 3.5. This would require the use of approximately 0.27 pound of 96 percent sulphuric acid per ton of sea water. In operation of the tribromoaniline process, already mentioned, it had also been found that it was desirable to add acid to the raw sea water before adding the chlorine, but a greater proportion was employed.

Figure 1 shows the variation in pH of raw sea water as affected by the addition of acid. Figure 2 shows the effect of variation of pH on the percentage of total bromine that can be liberated from the sea water by chlorine oxidation. Figure 3 indicates the effect of variation of pH of sea water on the chemical equivalents of chlorine required to liberate one equivalent of bromine. Figure 3 shows that, at a pH of 3.5 or less, the theoretical mole of chlorine was required per mole of bromine which was liberated.

With the knowledge at hand of the definite proportion of acid which would have to be added to sea water in order to promote a highly efficient process, the next research problem which arose was that of developing a means of immediately and continuously indicating the progress of oxidation in the chlorination step, so that the degree of liberation of bromine could be ascertained at any time.

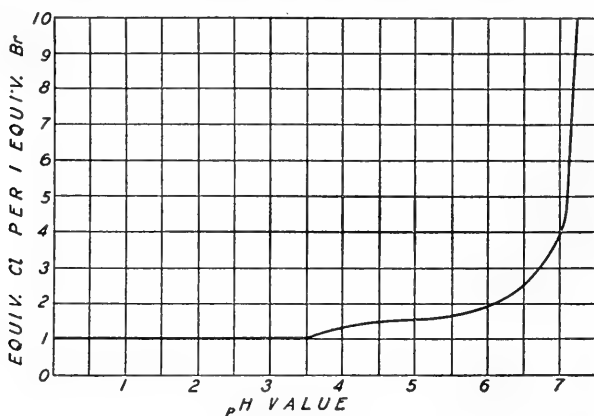


FIG. 3

EFFECT OF pH ON CHLORINE REQUIRED TO LIBERATE BROMINE IN SEA WATER

With the use of the ocean as a source of bromine, such enormous quantities of water were involved that, without some such control method, together with a method of continuously recording acidity, large losses of chlorine and acid would be sure to occur before the operator would realize what was happening. A method was finally developed which answered all requirements.

The new method of oxidation control depended on the fact that for every type of bromide-containing solution there is a characteristic range of oxidation potential values. This range depends on the initial concentration of bromine ions and also upon the collective effect of other ions present. It was found that, in acidified sea water, the first traces of free bromine in a solution that was being tested caused an immediate increase in oxidation potential. This rise was meas-

ured by the difference in voltage between a saturated calomel electrode and a platinum electrode. Figure 4 shows the relationship between the oxidation potential, expressed in volts, and the percentage of bromine liberated in sea water which contained about 3.5 percent total solids in solution and about 60 to 70 parts per million bromine, and which had been acidified to a pH of 3 to 4. The characteristic potential under these conditions ranged between 0.88 and 0.97 volt. The methods of extracting bromine from sea water, involving the control of acidification and oxidation, are protected by patents (3).

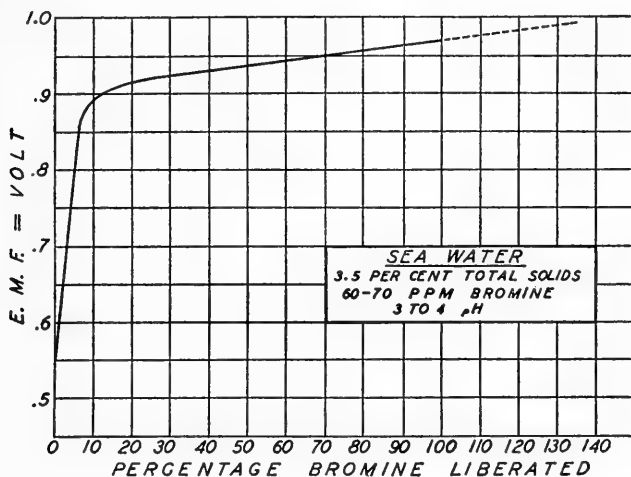


FIG. 4

RELATIONSHIP BETWEEN OXIDATION POTENTIAL AND
PERCENTAGE OF BROMINE LIBERATED IN SEA WATER

After obtaining a clear understanding of the factors which made for the most efficient liberation of bromine from sea water and development of satisfactory control methods, the laboratory and semiplant work on the process progressed much more rapidly. This work established the fact that air, blown countercurrent through a 70 parts per million bromine solution, would remove the halogen sufficiently to leave a concentration as low as 5 parts per million. It was also found that soda ash solution would effectively remove the very low concentration of bromine from the air. In these experiments, performed at Midland, Mich., synthetic sea water was used at first, and this was followed by tests made on tank-car shipments of true sea water. The chief result of the small-scale work was the demonstration that more than 50 percent of the bromine in the real sea water could be extracted and actually collected as the pure liquid. The indicated cost of operating the process seemed satisfactorily low.

SELECTION OF PROCESS AND PLANT SITE

Considerable other research work was done before the final process was selected. Other natural waters, as well as sea water, were investigated as sources of bromine, and improved methods were devised for their use. More economical methods in conjunction with the liberation of bromine were studied, including the use of lime or metallic iron to remove bicarbonates from solution and thus to save acid. Many different processes for removing bromine from very dilute solutions were tried extensively in the laboratory, some on semiplant scale. These included precipitation (1), extraction, and vaporization of the bromine as well as its absorption and adsorption in various agents, particularly in charcoal (2). While some showed fair success, the technic of blowing the bromine from solutions as dilute as the tailings from previous practice was improved and developed to a sound process as already described. Various methods were devised for recovering the bromine from the blowing-out air by both physical and chemical means, including immediate reaction of the bromine with ethylene. It is possible that some such improvements may be employed in the next few years. Finally, the commercial phases of correlating this industry with others were given careful study, and publication of the more interesting and important possibilities may be expected.

A comparison of the two general methods of obtaining bromine from sea water indicated that the direct extraction process possessed several economic advantages over the tribromoaniline method:

1. The direct process requires theoretically only 1 mole of chlorine for each mole of bromine which is liberated, whereas the other scheme requires 2 moles of chlorine per mole of bromine.
2. Smaller quantities of sulphuric acid are required by the direct process than by the other method.
3. Aniline is a relatively expensive raw material and is at a further economic disadvantage as a carrier of bromine for gasoline treatment when it is considered that tribromoaniline contains only 73 percent bromine, whereas ethylene dibromide is 85 percent bromine.

At this point in the history of the development it was decided to build and operate a pilot plant for extracting bromine from sea water by the Dow Chemical Company's process. The site for this unit was selected after considerable careful investigation, as it was proposed to build a commercial plant in the same location if the results of this venture were satisfactory. The chief requisites for such a site were:

1. The sea water at the point selected should not be diluted by fresh-water streams.

2. The location should be such that it would be easy to get rid of the sea water from which the bromine had been extracted, without diluting the water entering the process.

3. There should be no appreciable quantities of industrial waste present in the water entering the process.

A thorough study was made of the eastern and southern coast lines of this country. In this connection information learned from United States Coast and Geodetic Survey, to the effect that the water of all streams entering the Atlantic Ocean flows southward, was of considerable assistance. Many samples of sea water were analyzed, and, except where dilution with fresh water was indicated by a study of the location from which the sample was taken, the bromine content was found to be 67 parts per million. Before construction of the commercial plant, about 20 samples were taken during a boat trip from New Orleans to Havana and then to New York. The same bromine content of the deep-sea water was found throughout the entire distance.

The various factors involved in the selection of the plant site all indicated that it should be located on the north shore of a river, close to the point where it entered the Atlantic Ocean, and that there should be no large river entering the ocean for a number of miles to the north of such a location. The long narrow peninsula in North Carolina at the mouth of the Cape Fear River, which separates the latter from the ocean, appeared to answer all the above requirements. Consequently, a large tract of land was acquired near the southern end of this peninsula, and in 1931 a pilot plant was constructed and operated to extract 500 pounds of bromine per day from sea water. The bromine was absorbed in soda ash solution to form a bromide-bromate liquor from which bromine could have been liberated by acidification. Operation of this small unit for 6 months furnished valuable experience which aided in the design of the commercial plant which was to follow.

CONSTRUCTION DATA ON COMMERCIAL PLANT

About the middle of July 1933 the Ethyl-Dow Chemical Company was incorporated and the decision was made to construct a plant having a capacity to extract about 15,000 pounds of bromine per day from sea water and to manufacture it into somewhat more than 16,000 pounds of ethylene dibromide per day. Within a period of 5 months the plans were drawn, materials assembled, and the plant built and put into operation. The design and construction was executed by the Dow Chemical Company organization with the exception of some of the common building operations which were let on contract.

It is believed that this is an achievement in chemical engineering which is worthy of note, as the following facts relative to the construction of the plant will testify:

Clearing of ground started.....	July 27, 1933
Land cleared, acres.....	90
Ground broken for first building.....	Aug. 15, 1933
Production of ethylene dibromide commenced.....	Jan. 10, 1934
Wood piles driven (30 feet long).....	1,800
Sheet steel piling (36-50 feet long), tons.....	750
Excavation, cubic yards.....	125,000
Dredging, cubic yards.....	100,000
Concrete, cubic yards.....	8,892
Reenforcing steel, tons.....	425
Structural steel, tons.....	350
Electric conduit, miles.....	9.5
Electric wiring, miles.....	38
Brick laid.....	3,540,764
Maximum number men employed at one time, approximate.....	1,500
Approximate total of man-days.....	90,000
Building days.....	150
First working drawing completed.....	Aug. 14, 1933
Last working drawing completed.....	Nov. 2, 1933
Number of principal drawings (24 by 36 inches).....	265

The construction facts become even more impressive when it is realized that the nearest railroad shipping point is at Wilmington, approximately 20 miles away. Consequently the large quantities of materials which were involved had to be trucked that distance to the construction site. In order that the work might proceed rapidly, a considerable number of engineers and superintendents were required. These were accommodated in a nearby 50-room beach hotel which was leased and operated by the Ethyl-Dow Chemical Company.

Shortly before the construction work was completed, a wharf was built and a channel was dredged out to the navigable part of the Cape Fear River so that boat transportaion could be used for delivering operating supplies to the plant. The boat that has been acquired for this purpose is 116 feet long and is propelled by a 100 horsepower Diesel engine. It has a capacity of about 140 tons. One of its chief cargoes is sulphuric acid which is carried in special tanks installed below deck. The trip from the plant to the dock in Wilmington requires from 2 to 4 hours.

Figure 5 is a flow sheet showing the scheme of operations. Figure 6 shows the general layout of the plant.

OCEAN WATER INTAKE, CANAL, AND POND

The design and construction of the ocean water intake offered an opportunity for ingenuity and engineering foresight. No plans or

descriptions of a structure such as it was desired to construct were available. Experience obtained in putting down an intake pipe for the pilot plant indicated that a single row of piling would not survive the pounding of the ocean waves. It had been found, however,

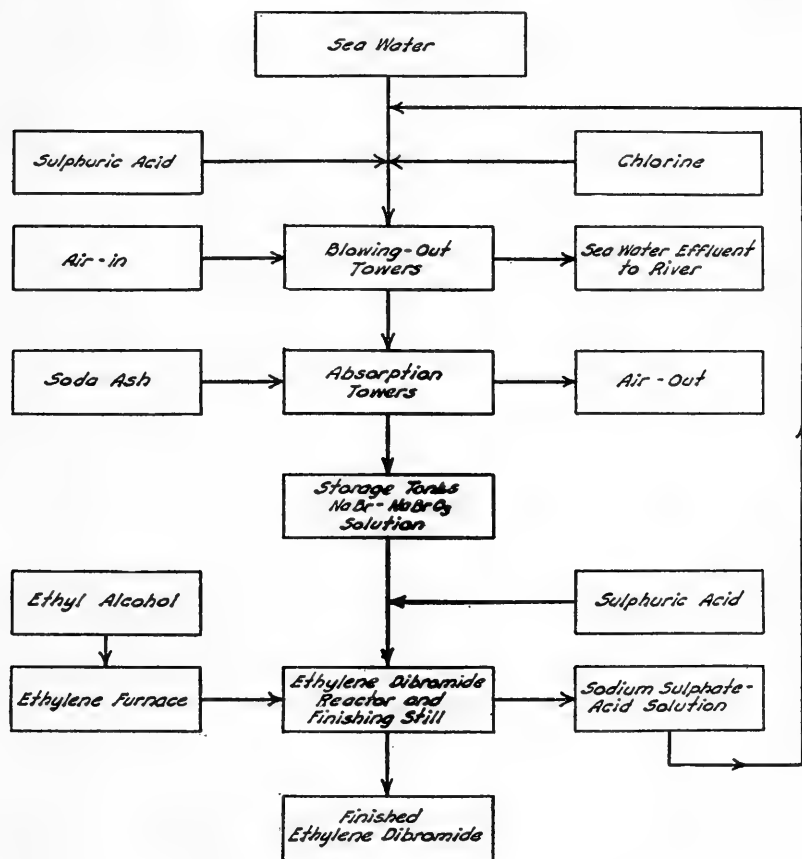


FIG. 5
FLOW SHEET
*Ethylene Dibromide from Bromine
Extracted from Sea Water*

FIGURE 5.—Manufacture of ethylene dibromide from bromine extracted from sea water.

that a row of piling on each side of the pipe remained rigid when tied together with a large number of crosspieces. In planning the intake of the new plant, it was decided, therefore, to cut a channel out into the ocean for a short distance and to protect it with a rigid wall on each side. The walls were each to consist of two parallel rows of piling tied together at suitable intervals.

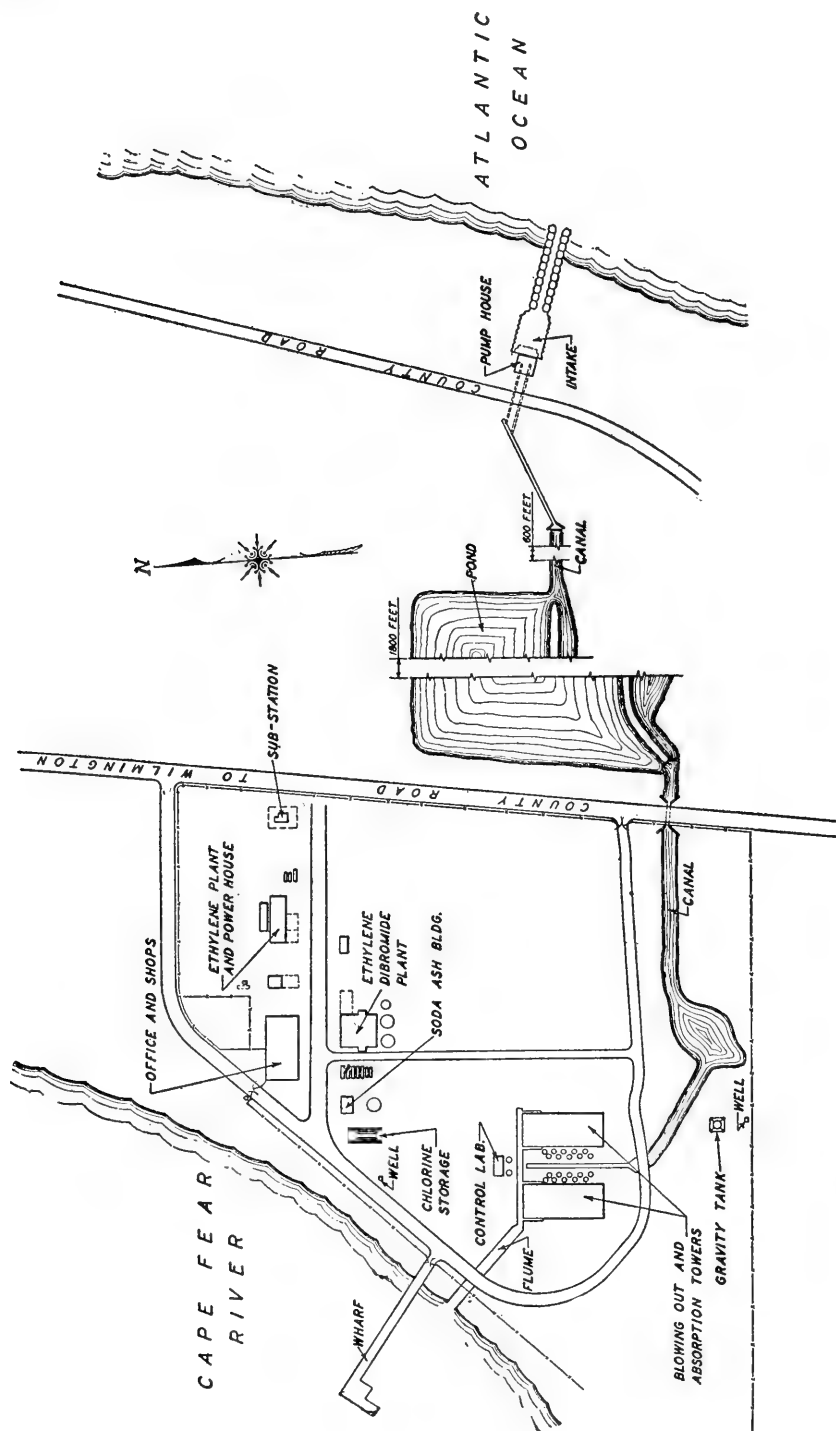


FIGURE 6.—Layout of plant for extracting bromine from sea water and manufacturing it into ethylene dibromide.

In constructing the intake walls, 50-foot lengths of interlocking sheet steel piling were used. These were driven to a depth of about 42 feet below mean low-tide level. The parallel rows of piling in each wall were joined together at every tenth member by a partition of similar piles at right angles to the direction of the wall. Consequently, when completed, each wall of the intake consisted of a series of interlocked cells 21 feet long and 15 feet wide. These were built, one at a time, beginning at the shore end and were filled with sand that was dug from the channel between them.

Altogether the intake (pl. 1, fig. 2) is about 200 feet long. It extends approximately 30 feet out into the ocean at low tide and about the same distance onto the land at high tide. The channel between the walls is 15 feet wide and the depth is 9 feet below mean low-tide level.

The sea water flows through the intake into a settling basin which is 112 feet long, 76 feet wide, and 12 feet deep. The walls in this case were formed from a single row of 40-foot steel piles. These were left with about 14 feet exposed above mean low-tide level and are about level with the surrounding ground.

The walls of the settling basin had to be supported from the outside in order to keep them from collapsing toward the inside. This was accomplished by bolting 24-inch I-beams to every eighth piece of piling and extending 2.5-inch steel rods about 30 feet out from each I-beam to anchor into timber piling which served as "dead men" to absorb the thrust of the dirt against the piling wall.

In putting down the steel piles, considerable difficulty was experienced in driving the first few members. When these were in place, it was found expedient to use water jets to aid in sinking the subsequent units. A 0.75-inch nozzle was carried down on each side of the piles, and, by forcing the water through the nozzles at 100 pounds per square inch pressure, it was possible to drive them a considerable distance merely by raising and dropping them. When the power required to raise a pile became too great for the derrick, the jetting was continued and a hammer applied to the top of the pile until the latter was driven to the desired depth. In order to keep the piles of the intake walls in perfect alignment so that there would be no difficulty in tying-in the cross partitions, a frame was constructed which was suspended in the air and which kept the piles perfectly straight in their desired location.

Four concrete compartments were built along the end of the settling basin opposite the intake. At the present time three of these are closed off with plank bulkheads to keep out floating debris. The fourth compartment has installed at its entrance a 120-inch Link-

Belt traveling screen which removes floating sticks and other foreign matter.

The pump house, adjacent to these concrete wells, contains two 30-inch centrifugal pumps. One of these has a capacity of about 26,000 gallons per minute, and the other can deliver approximately 32,000 gallons per minute. They are operated by 300-horsepower synchronous motors. The intake pipe for the pumps extends 9 feet below the water level at low tide, whereas the screens operate to practically the full depth of the compartment, which is 3 feet lower. In starting the pumps a Nash Hytor vacuum pump is employed to prime them. Three to five minutes are usually required to accomplish priming by this method. An interior view of the pump house appears in plate 2, figure 1.

Each of the centrifugal pumps is connected to a separate 42-inch steel pipe line which carries the water under a road into a 72-inch steel pipe. The latter conducts the water up over a concrete dam (pl. 2, fig. 2) into a canal and pond. The purpose of the dam is to prevent the emptying of the canal and pond back into the ocean when the pumps are not in operation. The top of the dam is at a level of 23 feet above mean low tide.

The canal is about 6 feet deep and extends about 4,000 feet across the peninsula to the plant, which is located close to the shore of the Cape Fear River. Approximately 2,200 feet of the canal are diked off from a pond through which the sea water is bypassed during the summer months. With some 900,000 square feet of exposed surface, the pond permits an increase in temperature during warm weather. This increases the efficiency of the process during several months of the year. After the water has been pumped over the dam and into the canal or pond, it flows to the extraction plant with a loss in head of only about 3 inches. A view of the canal and pond is shown in plate 3, figure 1. The pilot plant is visible near the far left-hand corner of the pond.

BROMINE EXTRACTION

The extraction of bromine from sea water takes place in two identical units which are located at the exit of the canal. A diagram of one of them is shown in figure 7. Each unit consists chiefly of a blowing-out tower in which a current of air removes the bromine from acidified and oxidized sea water, and an adjacent absorption tower in which the bromine is extracted from the air by means of a soda-ash solution. The towers are built of brick and have concrete floors and foundations. The foundations of each unit cover an area 197 by 84 feet. Wood piles 30 feet long were driven in the ground beneath the foundations to avoid any possibility of their settling.

The original ground where these structures are located was excavated to a depth of 9 feet or to a level which is about 5 feet above the river at low tide. This was done to minimize the height that the sea water would have to be pumped to the top of the blowing-out towers.

A horizontal steel flume, which is semicircular in cross-section and 10 feet in diameter, extends between the two extraction units and connects with the canal which brings in the sea water. Because the bases of the towers and the area between them are below the canal level, the flume is carried on steel supports so that it is at the same level as the canal (pl. 3, fig. 2). The absorption towers are located at the end of the flume which is nearest the canal. Hence, the water passes by them on its way to centrifugal pumps which elevate it to the tops of the blowing-out columns. Before entering the pumps, however, the water flows through a traveling screen at the end of the flume. This filters out any leaves or debris which may fall into the water after it enters the canal or pond.

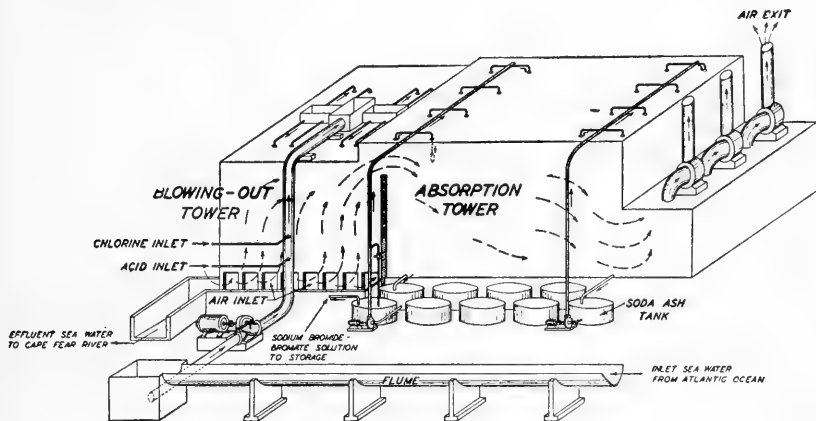


FIGURE 7.—Diagram of bromine extraction unit.

In each extraction unit the sea water is pumped to the top of the blowing-out tower through a vertical 42-inch rubber-lined pipe. Near the bottom of this, a 10 percent sulphuric acid solution is introduced into the water through a group of small rubber-lined pipes. A short distance higher the chlorine is introduced through similar rubber-lined pipes. At the top of the blowing-out tower the water passes through a series of large and small distributor boxes and pipes so that it eventually is divided up into about 3,200 small streams. These flow down through the tower, which is partitioned off into narrow chambers extending the full width of the structure. These chambers are filled with wood packing and are operated in parallel. A stream of air is sucked up through the tower countercurrent to the sea water. The bromine that has been liberated by the chlorine is thus blown out of the sea water, and the latter passes out of the bottom of the tower

through exit flumes to the river and thence into the ocean about 12 miles south of the intake. Plate 4, figure 1, shows a view of the exit flume.

The treatment of the sea water on its way to the blowing-out towers is regulated from the nearby control laboratory. Meters on a wall of the laboratory continuously show both the pH of the acidified sea water and its oxidation potential with respect to bromine liberation. Valves in the sulphuric acid and chlorine lines which lead to the 42-inch vertical mixing pipes are operated by hand from the control laboratory. At a later date it is probable that the control of these valves will be made automatic. Signal lights above the meters also indicate whether the condition of the treated sea water is correct for the blowing-out towers.

The chlorine which is used in oxidizing the sea water is obtained from cylinders having a capacity of 1 ton. A group of 16 of these is placed in each of 2 wooden compartments. These are kept at a temperature of not less than 70° F. The cylinders are connected to the chlorine line and their contents, in liquid form, flow to the chlorine vaporizer. This is a steam-jacketed iron pipe and is located adjacent to the control laboratory.

The sulphuric acid is delivered to the plant in the concentrated form, but it is diluted to a 10 percent solution before it is added to the sea water. This dilution is accomplished in two rubber-lined tanks, 16 feet in diameter and 10 feet high. These are located adjacent to the control laboratory.

In each extraction unit the air from the blowing-out tower is drawn through its adjacent absorption tower by three fans which are located on a concrete platform at the end of the unit. The air, just before entering the fans, passes through a small wood-filled chamber which catches any spray of soda ash solution that might otherwise be carried out of the system.

In the absorption tower the bromine is removed from the air by a soda ash solution to form a dissolved mixture of sodium bromide and bromate according to the formula:



The absorption towers are built on reenforced concrete arches which elevate their floors so as to permit gravity flow of the dissolving liquor into tanks which are located at their bases. This construction also makes possible the detection of any leakage which might take place in the tower bases at any future time.

Each absorption tower is divided into nine chambers which are connected in series so that the air, passing in at the end adjacent to the blowing-out tower, follows in succession through these absorbing

chambers and out through the suction fans. Soda ash solution is circulated continuously in each chamber. This is done by pumping it from a tank at the bottom and spraying it in at the top through 36 nozzles, from which it falls by gravity and drains again into the tank.

At proper intervals the strong bromide-bromate solution formed in the absorption chamber adjacent to the blowing-out tower is pumped to a storage tank. The charges of partially brominated soda ash liquor in the other members of the series are then pumped forward, in turn, to the next tank nearer the one which has just been emptied to storage. When the tank farthest from the blowing-out tower has been emptied, it is charged with a fresh solution of soda ash. Plate 4, figure 2, shows the south end of the bromine extraction plant. Plate 5, figure 1, is a view looking down on the absorption liquor tanks, and plate 5, figure 2, shows the battery of pumps which circulate the soda ash solution. The inlet flume may be seen overhead.

After the bromine from the sea water has been collected in the form of a solution of sodium bromide and bromate, the remainder of the process is performed according to methods which have been previously in use in the industry. The bromide-bromate liquor is treated with sulfuric acid to liberate the bromine. The free bromine vapors are then steamed out of the acidified solution and are condensed into pure liquid bromine. Plate 6, figure 1, shows the plant in which the bromine is finally obtained in liquid form. The two bromide-bromate liquor storage tanks are seen at the side of the building and the horizontal sulfuric acid storage tanks are in front of it.

The bromine is used in the manufacture of ethylene dibromide, which is also made in the building shown in plate 6, figure 1. Ethylene is made by passing ethyl alcohol vapor over heated kaolin catalyst to form ethylene gas, which is in turn brominated according to the standard method to form pure ethylene dibromide. Plate 6, figure 2, shows the ethylene plant and powerhouse, which are both in the same building. The battery of valves for controlling the ethylene production is shown in plate 7, figure 1. A consignment of finished product on the shipping platform of the ethylene dibromide plant is shown in plate 7, figure 2.

The powerhouse employs hand-fired boilers and makes steam only for heating and evaporating purposes. Its capacity is about 15,000 pounds of steam per hour at a pressure of 150 pounds per square inch. Operating electric power is purchased from the Tidewater Power Co. It is delivered to the plant at 33,000 volts, where it is stepped down to 2,300 volts in two transformer banks.

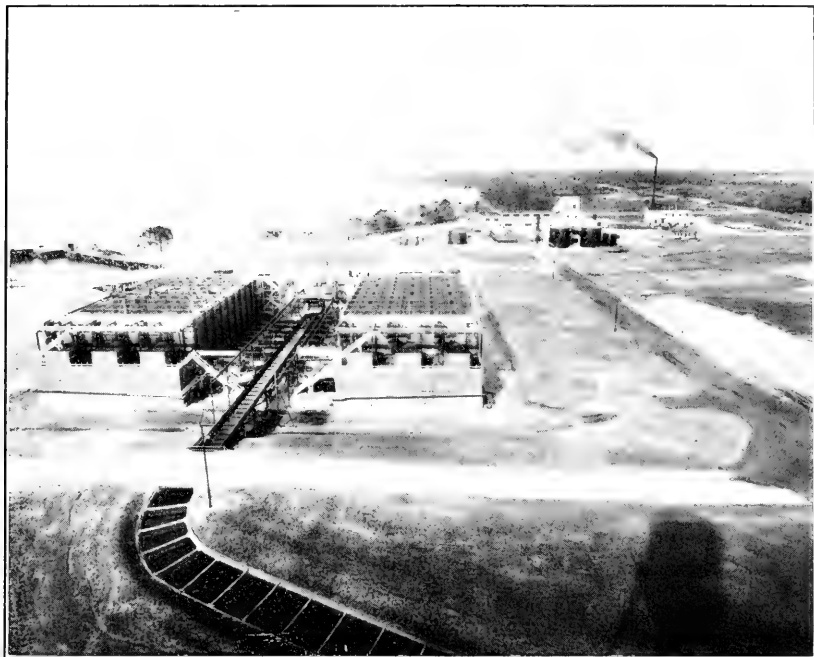
The entire plant is functioning as anticipated and is removing about 15,000 pounds of bromine per day from sea water. This is

being converted into ethylene dibromide at an efficiency somewhat over 90 percent.

The direct recovery of minerals for industrial use from sea water has long held the attention of chemists, and it is believed that the plant which has been described is the first to accomplish this achievement on a commercial scale of operation. The extraction of gold from sea water, in which it is present to the extent of but a few parts per billion, has always been the investigator's most fascinating goal, but no success along this line has been reported thus far. Now that the recovery of bromine, which is present to the extent of less than 70 parts per million, has been successfully executed, it does not seem beyond reason to expect the chemist of the next decade to extract gold from sea water commercially.

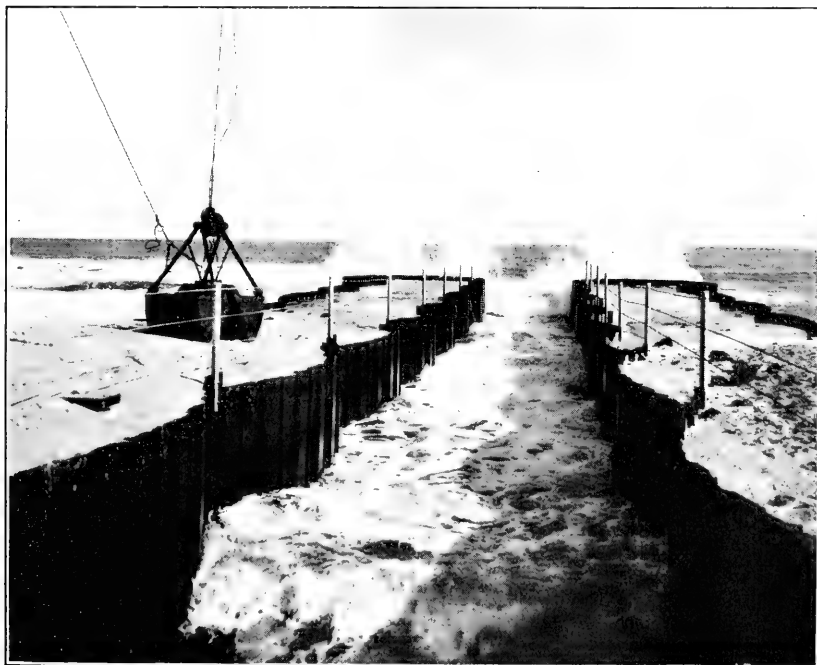
LITERATURE CITED

- (1) Grebe, J. J., United States Patent 1891888 (Dec. 20, 1932).
- (2) Grebe, J. J., and Boundy, R. H., *Ibid.*, 1885255 (Nov. 1, 1932).
- (3) Grebe, J. J., Boundy, R. H., and Chamberlain, L. C., *Ibid.*, 1917762 (July 11, 1933) ; Grebe and Boundy, *Ibid.*, 1944738 (Jan. 23, 1934).
- (4) Stine, C. M. A., *Ind. Eng. Chem.*, vol. 21, pp. 434-42, 1929.

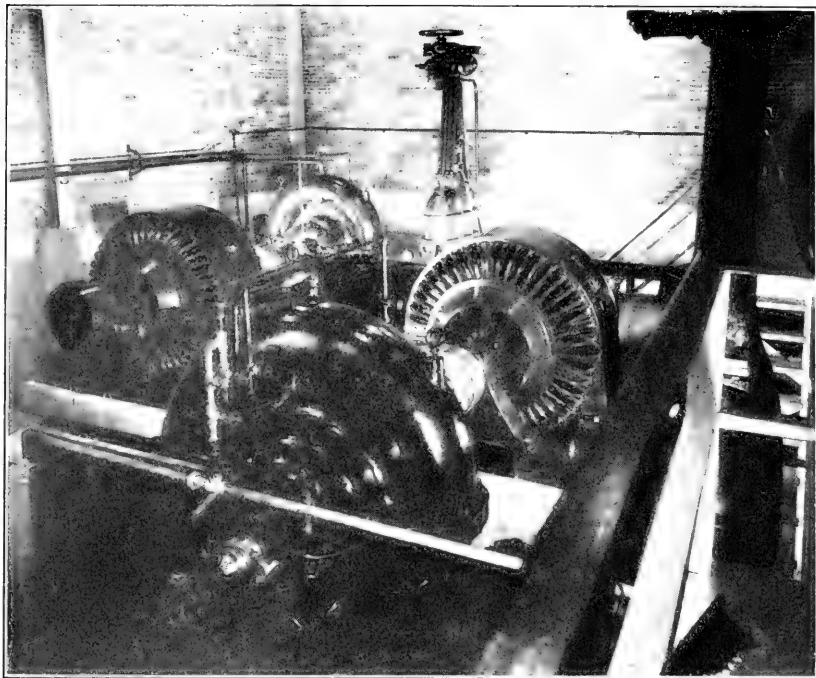


1. PLANT FOR EXTRACTING BROMINE FROM SEA WATER AND MANUFACTURING IT INTO ETHYLENE DIBROMIDE.

(Compare figure 6.)



2. SEA-WATER INTAKE.



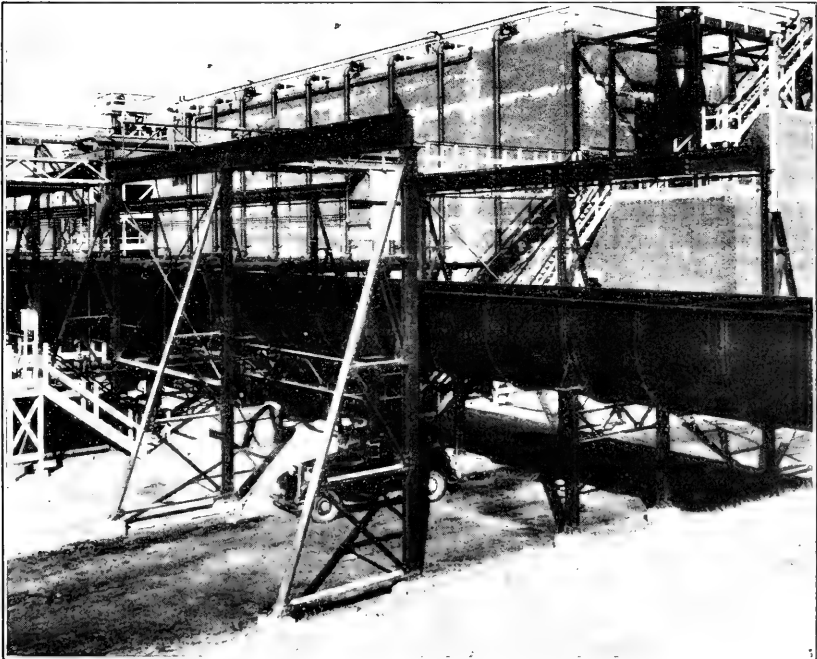
1. INTERIOR OF PUMP HOUSE AT SEA-WATER INTAKE.



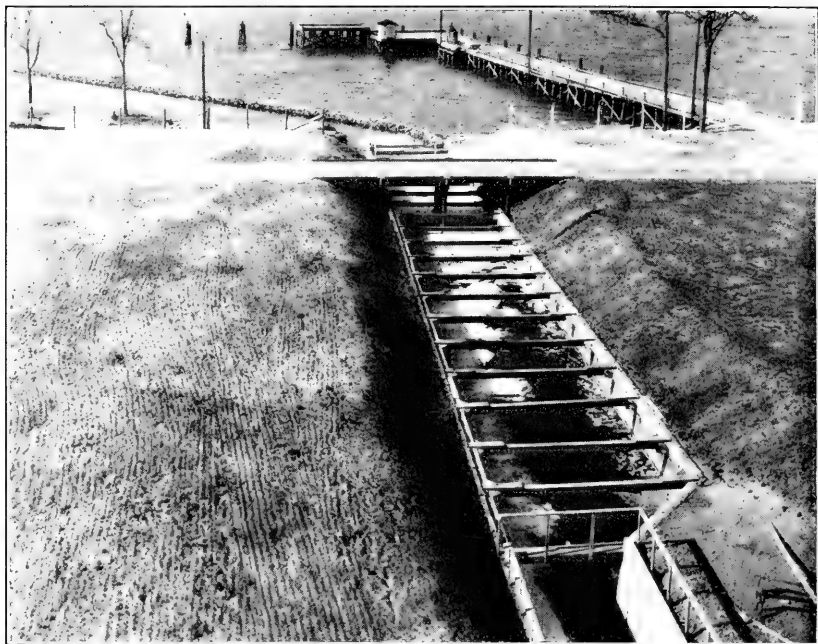
2. SEA WATER BEING PUMPED OVER DAM AT RATE OF 58,000 GALLONS PER MINUTE.



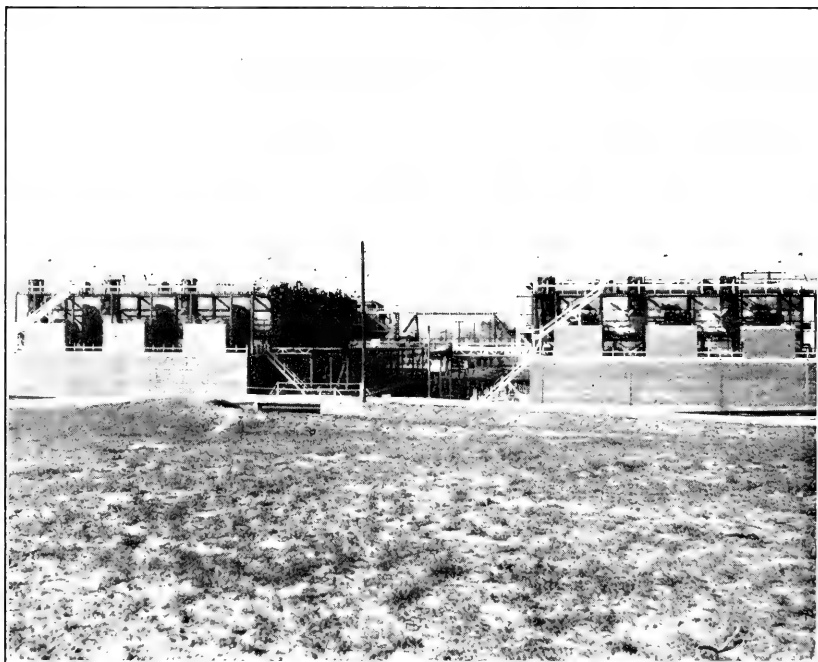
1. CANAL AND POND FOR PASSING SEA WATER TO BROMINE EXTRACTION PLANT.



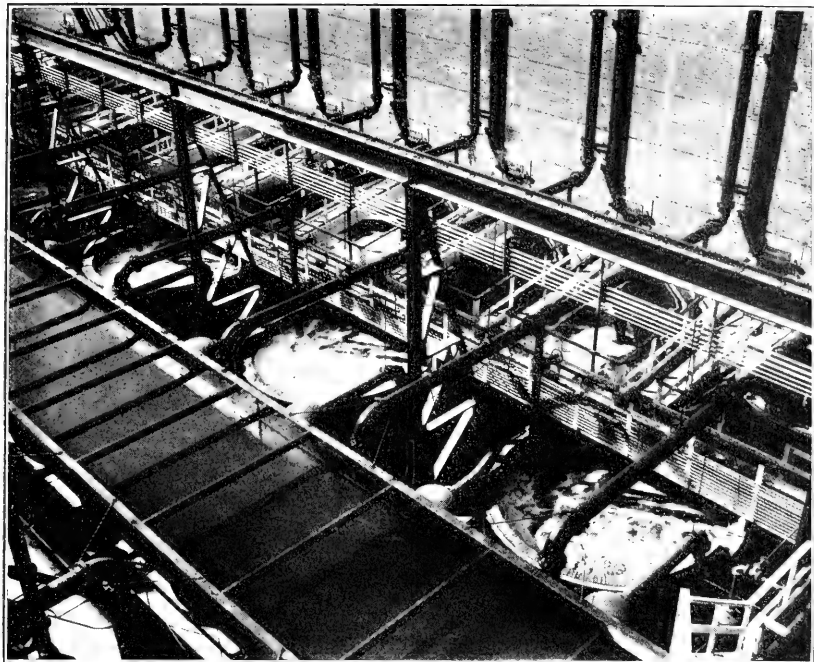
2. FLUME FOR CONDUCTING SEA WATER TO BLOWING-OUT TOWERS.



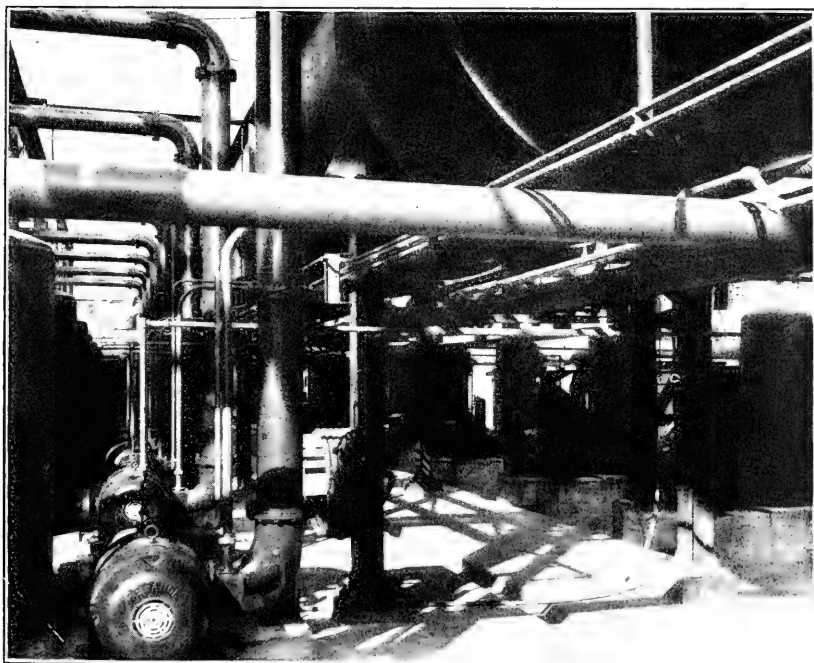
1. EFFLUENT SEA WATER PASSING FROM BLOWING-OUT TOWERS TO RIVER.



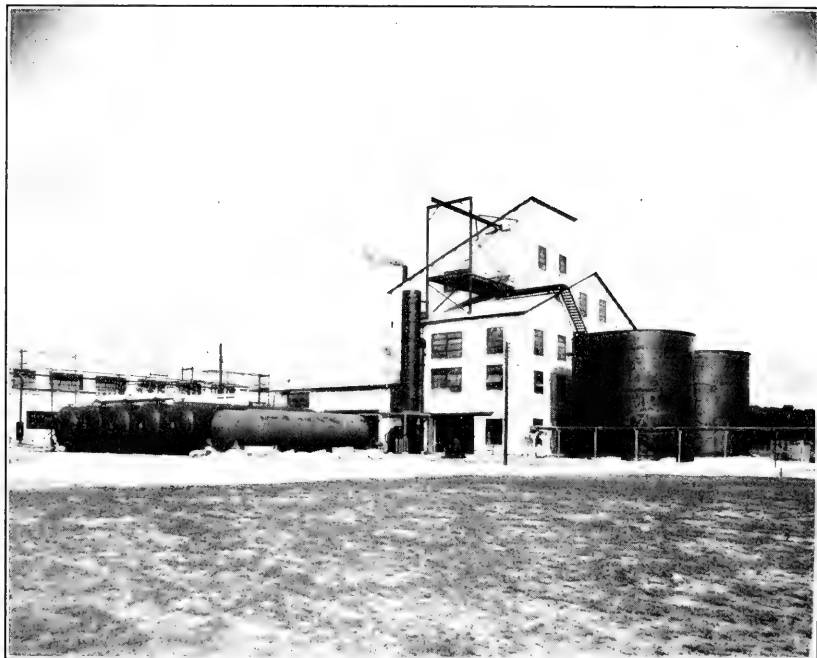
2. SOUTH END OF BROMINE EXTRACTION UNITS.



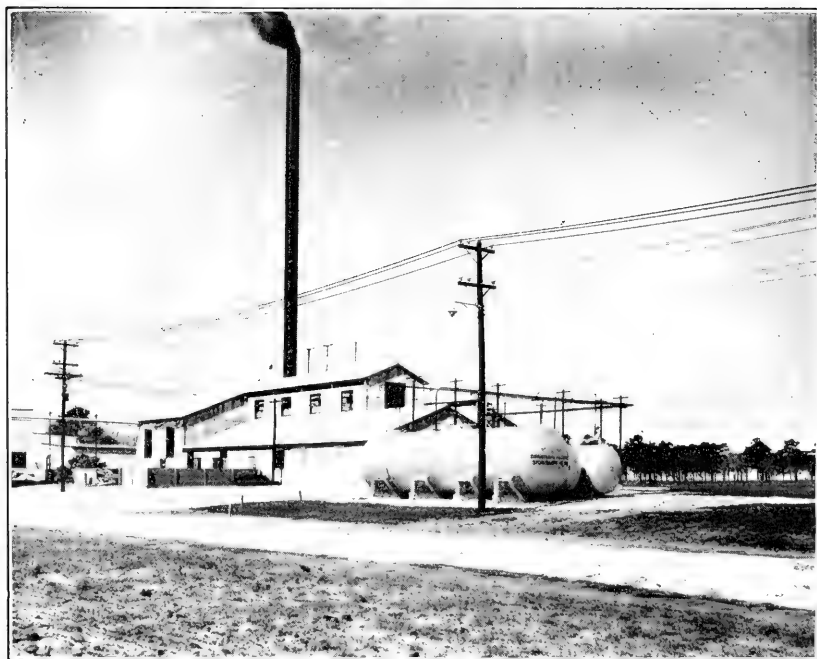
1. LOOKING DOWN ON BROMINE ABSORPTION LIQUOR TANKS.



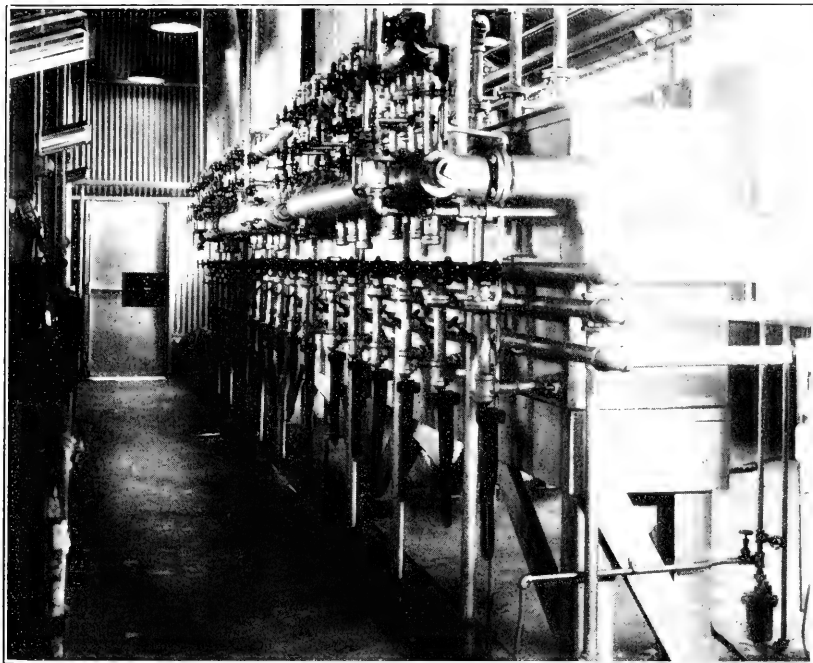
2. BATTERY OF PUMPS FOR CIRCULATING BROMINE ABSORPTION LIQUOR



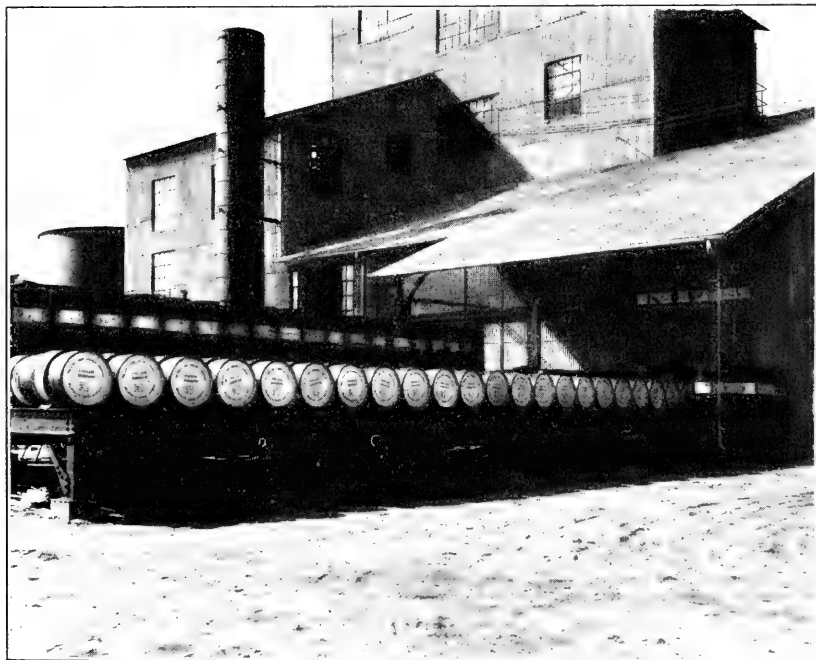
1. BROMINE AND ETHYLENE DIBROMIDE PLANT.



2. ETHYLENE PLANT AND POWER HOUSE.



1. BATTERY OF VALVES FOR CONTROLLING ETHYLENE PRODUCTION.



2. SHIPMENT OF FINISHED ETHYLENE DIBROMIDE.

BEFORE PAPYRUS . . . BEYOND RAYON¹

By GUSTAVUS J. ESSELEN, PH. D.

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Boston, Mass.*

We wear it; we live in houses made of it; we record our news and literature upon it; we even take it into our systems with our food. What is it? The answer to this riddle is a material which has been responsible for epoch-making changes in the trend of human affairs throughout the long road up from savagery through barbarism and early civilization to the present time. Everyone is familiar with it, yet few know it. It is not only the most abundant material of the vegetable kingdom, but it is also one of the most important materials on which man has relied throughout the development of civilization. We know it in the forms of cotton and of linen; of wood and of paper. We even know it as artificial silk. Yet reference to cellulose, which is the basic chemical substance common to all these materials, brings in a word which is familiar to few. On the other hand, this term cellulose is one destined to become gradually more and more familiar, at least to those who make any pretense of following modern trends in the arts and sciences.

Cellulose has not only exerted an unusual influence on the progress of mankind in the past, but today it is the basic raw material for great industries. Since it forms the structural framework of all trees and plants, it is available wherever vegetable life occurs. Furthermore, it is one of the few raw materials which is capable of periodic reproduction in enormous quantities, and for this reason, if for no other, seems destined to take an increasingly important part in the industrial development of the world.

Since cellulose is so common in nature, it is only natural that it should have played an outstanding role in the history of mankind from the time that early man took the first step out of savagery by accidentally learning how to burn it, until, in the form of a

¹ Reprinted by permission from the Journal of the Franklin Institute, vol. 217, no. 3, March 1934. Presented at a meeting of the Franklin Institute held Thursday, Oct. 26, 1933.

"scrap of paper" it was responsible for developments leading to the Great War in 1914.

Civilization proper is generally considered to have begun with the development of a system of writing, perhaps 10,000 years ago. For this, cellulose can claim no credit, since early writings were on clay and stone long before the advent of papyrus. However, when in more recent years cellulose, as paper, became the silent bearer of the written and later the printed word, it became the messenger of the guiding forces of civilization. It is in this role that cellulose has reached its highest significance, making possible many things which had not been feasible before, through the easy and ready dissemination of information to great masses of people.

At about the same time that the manufacture of paper was being introduced into Europe there were also other developments dependent upon the use of cellulose which were of such outstanding importance as to have changed the whole trend of civilization. It was in the thirteenth century that Roger Bacon² first described black powder, to which he gave the name "philosopher's egg." How strikingly time has shown the aptness of this picturesque title and what events of first importance have been hatched from it! When used in guns, as it was in the fourteenth century, it put a new power in the hands of the common people and changed the entire social system. Truly did Bacon write, referring to his anagram in which he gave the secret of gunpowder, "Whoever will rewrite this will have a key which opens and no man shuts; and when he will shut, no man opens." And an essential part of this "key" was charred cellulose. Again the ready availability of cellulose contributed its part to an epoch-making step in the advance of civilization. Even today charcoal from willow and beech is preferred for the manufacture of black powder.

It has been said that this particular period was a great period of leveling; that gunpowder was a great leveling influence downward for the mighty and that the printed page was a great leveling influence upward for the lowly. At any rate paper has now come into universal use throughout the civilized world. It may be only to wrap a bundle or it may be to record a thesis which starts a reformation. It may be to carry a love message or it may be to announce a declaration of independence. It may be merely the kindling which lights the fire on the hearth or it may be the scrap of paper which starts a world conflagration.

To be sure, paper had been known in China for several hundred years before the Christian era, but its use was not established in Europe until about the twelfth or thirteenth century. The story is

² Davis, Ind. and Eng. Chem., vol. 20, p. 772, 1928.

told that the Arabs were attacked by the Chinese in Samarkand about the middle of the eighth century. The Arabs repulsed their enemies and succeeded in capturing some of the Chinese who knew how to make paper and from them learned the secret. The knowledge of papermaking spread rapidly in Arabia as is evidenced by the fact that there are many early Arabian manuscripts on paper still preserved today, the earliest being dated A. D. 866. Trade with Asia seems to have been responsible for bringing a knowledge of paper manufacture to Greece at about the end of the eleventh century, and the Moors established it in Spain in the middle of the twelfth. It gradually spread to Italy, Germany, and France, so that by the year 1350 the manufacture and use of paper was well established in Western Europe and vellum was gradually superseded.

Today we have many grades and kinds of paper, but all are composed mainly of cellulose, of degrees of purity which vary with the particular kind of paper. At first all paper was made from cotton or linen rags, but during the last century wood has become the chief source of supply through the development of chemical methods for separating the cellulose from the other constituents of wood. In 1932 in the United States alone there were consumed about 4,000,000 tons of wood pulp which represents about 9,000,000 tons of wood. Of this, a little more than half was of domestic production and the balance imported. The use of a natural resource at so rapid a rate has naturally raised the question as to the steps which should be taken to prevent exhaustion of the supply. To some, the answer seems to be reforestation, while others prefer to rely on cutting trees only above a certain size. By leaving the smaller trees in this way, it has been demonstrated in several sections in the South that a 20-year crop cycle is perfectly feasible. Many experts believe that if the cellulose resources of the temperate zone should prove inadequate, the Tropics could be relied upon for an adequate supply. Already the rapid-growing bamboo of India is being converted into pulp, and studies are being made of the pulp possibilities of varieties of African trees which yield as much or more cellulose per acre per year.

Since cellulose forms the structural skeleton of all vegetable growth, attention is also being focused on annual field crops as possible sources of cellulose. Cornstalks were suggested for paper-making well over 100 years ago, and chemically this has been possible for a long time. However, it is only within the last few years that the economic problems of harvesting, collecting, and storage have received the scientific study which is essential if these problems are to be solved in such a way as to make the use of cornstalks economically feasible. The sugarcane also has been the object of considerable attention and many kinds of paper have been produced

from it. The application of scientific method in this case has demonstrated in actual farm tests that the per-acre yield of sugarcane can readily be increased fourfold to sixfold, and in special test plots the yield has been raised to 20 or 30 times the usual average. Even with present yields of corn it is estimated that the United States produces annually about 31,000,000 tons of cornstalks. This is dry weight, free from leaves and husks, and should yield, in the form of paper or board, about 9,000,000 tons, or a little more than the total amount of paper and paperboard produced in the United States in 1932. In other words, assuming the solution of economic problems, such as the collection at a central point of sufficient quantities to permit of operation on a proper scale and the storage of enough material to keep such a mill going for the better part of a year, it still would be necessary to find new outlets for cellulose to make the collection of any considerable proportion of the stover from our annual field crops economically desirable at this time.

In transportation as in so many other activities, man was long dependent on cellulose. His earliest boats, in the form of hollowed logs, were essentially cellulose, as were the paddles and later the oars that propelled them. The sailing ships on which man relied until so recently, were made of wood and the cloth of the sails was cellulose in a purer form. Even the modern ocean liner requires cellulose in the form of boat covers, collapsible boats, curtains, deck covering, fenders, hatch covers, life preservers, and tarpaulins, not to mention what might be termed the household requirements such as sheets, towels, upholstery, draperies, and table damask.

For land transportation, also, man long depended on cellulose. His early sledges and carts were of wood, as were also the stage coaches of a later day. The modern limited train, in which cellulose now is only of minor importance, is the outgrowth of experiments conducted only a hundred years ago in which the fuel was wood, the cars were of wood, and in some instances even the rails were of wood. When we turn to the modern automobile, so essential a part as the tires are quite as much cotton cellulose as they are rubber.

While for thousands of years man had turned to cellulose for so many of his needs, it had, until the last 100 years, always been as the naturally occurring cellulose or as the simple derived products, charcoal and paper. With the development of chemistry it was only natural that chemical derivatives of cellulose should begin to make their appearance. The surprising thing to any critical observer might be that the chemistry of cellulose was so slow in developing, since the use of cellulose itself was centuries old. To the

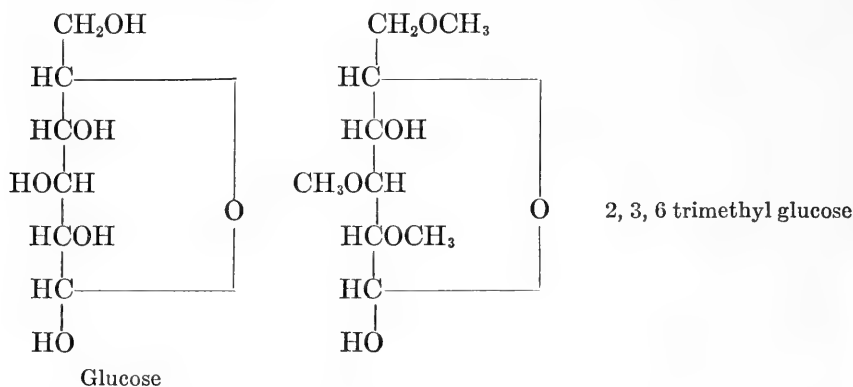
chemist, on the other hand, the reason is quite apparent, for it is only a relatively short time that even the empirical composition of cellulose has been known. For some time that was all the information available, since cellulose could not be crystallized nor could its molecular weight be determined. Little by little the chemistry of cellulose has been unfolded and although we do not yet know the whole story, it is nevertheless being recognized that in cellulose, mankind has a chemical raw material available in enormous quantities and a substance the supply of which can be annually replenished when economic conditions become such as to warrant it.

At this point it may be of interest to digress a moment to survey briefly the development of industrial organic chemistry. It started with the distillation products from coal as its raw material and separated from this complex mixture various substances of the so-called aromatic series, from which were synthesized at first dyes, and later perfumes and medicinals. In each case, however, the product was a definite solid or liquid compound with well defined molecular properties. About 10 or 12 years ago a second division of applied organic chemistry appeared, which has since grown to what might almost be called a heavy organic chemical industry. It starts with the simplest aliphatic hydrocarbons such as ethylene and builds up from there aliphatic products which find wide use in industry, many of them as solvents. The synthetic processes have even been carried to a point where various polymerized molecules have been produced to give solids with colloidal characteristics such as the vinyl resins and the so-called synthetic rubber. At this point this second division of applied organic chemistry meets the third, which uses cellulose as raw material. Here we have a substance which occurs naturally in the form of a highly polymerized molecule and the uses of it and its derivatives depend in large degree upon the retention of these colloidal properties.

In spite of the fact that industries using cellulose are centuries old, it is only for a relatively short time that we have known even that its empirical composition was $C_6H_{10}O_5$. At first, it was thought that there were four hydroxyl groups in the $C_6H_{10}O_5$ unit, and I can well remember a lively discussion at one of the meetings of the American Chemical Society not more than 12 years ago as to whether there were four hydroxyl groups or only three. It is now generally recognized, that there are only three hydroxyl groups in the elementary cellulose unit, but it was not until about 11 years ago that their character was known.

This question was answered very prettily by Denham and Woodhouse by repeated treatments of cellulose with dimethyl sulphate

in the presence of alkali. On hydrolyzing the methylated cellulose with weak acid they obtained chiefly 2, 3, 6 trimethyl glucose which may be represented



Since there are two free hydroxyl groups in the trimethyl glucose, it is apparent that these could not have been present in the original cellulose molecule but must have been produced during the hydrolysis. The methylated ones are the ones which were originally present in the cellulose and since the constitution of trimethyl glucose is known, it follows that in cellulose there must be three and only three hydroxyl groups, one of which is a primary hydroxyl group and the other two secondary. Since the empirical composition of cellulose is $\text{C}_6\text{H}_{10}\text{O}_5$ and that of glucose $\text{C}_6\text{H}_{12}\text{O}_6$, it is obvious that cellulose is made up of anhydro-glucose units.

This statement, however, would hardly suggest the exceedingly complex character of the cellulose molecule. Although externally cellulose and its derivatives always appear as amorphous or colloidal materials, nevertheless the X-ray has shown them to possess definite crystalline characteristics. The unit cell responsible for the crystalline properties is believed to consist of four glucose residues. It is now believed that these unit cells are bound together by primary valences into long chains of what might be termed anhydro-glucose residues, and that these primary valence chains are in turn bound together by secondary valence forces to form the micelle. This basic idea has been extended and elaborated to account for the structure of the cellulose fiber, including its high longitudinal strength, the orientation about the long axis of the fiber, and the presence of the outer layer of fibrils in the cellulose fibers from wood.

Thanks to recent investigations by Staudinger, by Freudenberg, and by Stamm, we even have some conception of the molecular weight of cellulose. While these figures do not agree, nevertheless, they at least indicate that the molecular weight is very high. Stau-

dinger, for example, has found that cellulose from purified cotton has a molecular weight of 190,000 and he feels that even this may be on the low side. Freudenberg has calculated the molecular weight to be in the neighborhood of 8,100, although he admits this is probably too low. Stamm, using the ultracentrifuge, has obtained a molecular weight in the neighborhood of 40,000.³ In this connection it is of interest to note that Staudinger and Schweitzer found that rayon made by the cuprammonium process has a molecular weight only about one-sixth that of purified cotton, and Stamm found that the cellulose in wood pulp consisted largely of material having a molecular weight about half that of cellulose from carefully purified cotton.

Although the use of cellulose as a technical raw material did not wait for our present-day knowledge of the structure of the cellulose molecule, nevertheless, the more we know about the inner chemistry of cellulose, the more rapidly do its uses expand.

The first chemical derivative of cellulose to assume importance in our present-day civilization was the nitrate. When a properly purified cellulose is treated with a mixture of nitric and sulfuric acids, a series of nitric acid esters of cellulose is formed. Those which contain about 11 percent of nitrogen are the basis of the pyroxylin plastics such as celluloid; those with about 12 percent of nitrogen are used for artificial leather and lacquer finishes; while those with a higher percentage of nitrogen constitute our smokeless powders. The significance of the last for present-day civilization needs no comment. The modern pyroxylin finishes, as represented by quick-drying lacquers, have been as effective in their way in increasing man-hour output as has power machinery in other ways. Nitrocellulose and cellulose acetate, as the basis of the moving-picture film, have given us a means of recording events in action and in sound as they previously had been recorded in story on cellulose in the form of paper.

One of the uses of transparent sheets of cellulose ester plastic which is now receiving considerable attention in the public eye is in the manufacture of laminated glass such as is finding increasing use in the modern automobile. This glass is made by cementing a specially prepared sheet of cellulose plastic material between two pieces of glass. The product as used in windshields is of about the same thickness as ordinary plate glass but it does not shatter nor do the pieces fly when the glass is broken. A further application of the same principle is in the manufacture of bullet-proof glass. This is

³ Since writing the above, the author has been advised privately that recent and more accurate determinations have placed the molecular weight of carefully purified cotton cellulose at 300,000.

composed of five laminations. The center one is usually a piece of plate glass about three-quarters of an inch in thickness. To each side of this is cemented a sheet of cellulose plastic and on the outside of each of these layers of plastic there is cemented a piece of thinner plate glass, making a composite piece a little over an inch thick. Such material resists bullets even at close range and is finding use in the windows of armored cars and cashiers' cages in banks. Up until very recently the plastic used for this purpose was made from cellulose nitrate. This was not ideal for the purpose because it gradually discolored in the light. However, considerations of cost compelled its use. Within the last year or so, however, a revolutionary change in the method of manufacture of these plastics has so lowered the cost of the finished sheets of cellulose acetate plastic that at the present time it is estimated that over 70 percent of all the laminated glass manufactured in this country is made with cellulose acetate plastic. The manufacturing improvement responsible for this surprising change consists in replacing a long series of batch operations by a single continuous process which cuts the time of production from 10 or 12 days to the corresponding number of hours; and since the material is totally enclosed during its manufacture, practically the total production is of first quality.

When attention is turned to the manifold applications of cellulose and its derivatives in modern civilization, it becomes quite apparent that cellulose is not only nature's riddle but also nature's paradox. Cellulose in the form of wood has long been used as a material of construction because of its resistance to atmospheric conditions, yet at temperatures slightly under that of boiling water, cellulose slowly combines with oxygen and decomposes. Again cellulose in the form of cotton is widely used for clothing because of its resistance to washing and to the chemicals usually used in that operation, yet two samples of cellulose, identical except that one has been boiled in distilled water for 2 hours and then dried, exhibit markedly different chemical characteristics.

We therefore find that to supplement the age-long uses of cellulose which have been dependent on its resistance to chemical change, there is now springing up a long list of uses which depend upon its chemical reactivity. If cellulose in the form of cotton thread or fabric is treated with an 18 percent solution of caustic soda in the cold and dried under tension, there is obtained the well-known effect of mercerization which produces a silky finish on cotton fabrics. On the other hand, if sulfuric acid of about 70 percent strength is used instead of the caustic soda and the acid thoroughly washed out, there is obtained the material known as vegetable parchment, which is sufficiently water resistant so that it has been sold to replace cloths

in dish-washing. Paper is the form of cellulose used for this treatment. When special forms of paper are employed, the product makes an excellent electric insulation. Treatment with concentrated solutions of zinc chloride produces a somewhat analogous effect, the product being known as vulcanized fiber which finds many uses in industry as for example in roving "cans" so-called, and trucks for textile mills.

For centuries cellulose in the form of linen and cotton has provided wearing apparel. Almost our earliest literature speaks of purple and fine linen. Yet silk was always the fabric of the nobility and had a beauty and a feel which the cellulose fibers could not match. Since the sheep converted the cellulose of hay and grass into wool and the silk worm changed the cellulose of the mulberry leaf into silk, man has long been trying to find the secrets, particularly that of the silk worm. The natural raw material with which to experiment was cellulose, at first that of the mulberry leaf and later a purified cellulose. While the silk worm's secret has not yet been found, ways have been developed, after years of research, for producing from cellulose fibers which are as attractive as silk to both eye and skin. In the four forms of rayon we have the first man-made fibers and fibers which, therefore, are not subject to the whims of nature for their production.

The goal for which the early investigators in this field were striving, was the production of natural silk by artificial means. In fact it has been said that its earliest designation, artificial silk, was given to the new product in order to distinguish the silk made by artificial means from that made by nature. It is well known now, however, that none of the four varieties of rayon are in any way related chemically to silk. The first three to be developed are all regenerated cellulose and quite similar in their properties, although the series of changes through which they have passed from cellulose to finished product are in each case quite different. The latest member of the group is cellulose acetate, a chemical compound of cellulose and acetic acid and quite different in its properties from either cellulose or the other forms of rayon.

In general the processes for the manufacture of synthetic fibers may be divided into two classes, depending upon whether the finished fiber is essentially cellulose, regenerated in a somewhat modified form, or whether it is a compound of cellulose such as cellulose acetate. All of the processes have certain underlying principles in common, involving first the conversion of the cellulose into a soluble derivative, the solution of which is then forced through very fine orifices into a hardening medium which may be either a liquid or a gas, depending upon the character of the solvent. In the earliest process,

the cellulose was converted to cellulose nitrate which was dissolved in a mixture of alcohol and ether, and this solution, after careful filtration, was squirted through fine orifices into a stream of warm air which caused the solvent to evaporate, leaving fine filaments of cellulose nitrate. The solvents were recovered and the fibers subjected to an alkaline saponification treatment for the purpose of reducing their inflammability. This left them finally in the form of regenerated cellulose. This process is now being used by only a single company in the United States.

Another process takes advantage of the solubility of cellulose in cuprammonium solutions. In this case the deep blue, viscous cellulosic solution passes from the fine orifices directly into a liquid regenerating bath which may be either a dilute acid or a dilute alkali. After being freed from copper, these fibers also are composed of regenerated cellulose.

The process by which at least 80 percent of the artificial silk is produced today, is the viscose process. In its barest outline it consists in treating purified cellulose with caustic soda solution, followed, after a suitable aging period, by treatment with carbon bisulfide which produces a cellulosic compound soluble in dilute alkali. This also is ripened and then squirted into dilute sulfuric acid which breaks down the soluble compound and regenerates the cellulose.

In all of these three processes it will be noted that the finished fibers are composed of a modified cellulose. In the fourth commercial process and the one which just now is expanding at the most rapid rate, the cellulose is converted into cellulose acetate and the finished fibers are composed of the same material. The solvent is usually acetone and the solution is ejected from the orifices into a stream of air in which the acetone evaporates and from which it is recovered. One of the advantages of this process is that the fibers require no further chemical purification treatment before they are ready for what might be called the textile operation of twisting.

When artificial silk first appeared on the market it was rather coarse and somewhat harsh in its feel. Since then, however, there have been marked improvements in the strength of the fibers and, also, there has been a general tendency toward reducing the size of the individual filaments as well as the size of the threads. Perhaps one of the most remarkable developments in the rayon industry in recent years has been the marked increase in the demand for fibers in which the normally high luster has been reduced. Originally artificial silk achieved popularity because of its high luster, yet today considerably more than half of all the rayon produced has the luster more or less reduced.

Still another trend which is worth noting, is the increasing popularity of synthetic fibers made from cellulose acetate. This was the last of the four varieties to achieve commercial importance, and at first its high cost deterred its wide use. Recently, however, there have been reductions in the price and with these have come wider markets.

When rayon, or artificial silk as it was then known, first began to attract attention in this country, a committee of silk manufacturers was appointed to study this new competitor and report on its possibilities. After careful deliberation the committee finally concluded that the possibilities of the new fibers were distinctly limited and that they would probably be short-lived. Yet in 1931 60 percent more rayon was used in the United States than natural silk and this year the proportion in favor of rayon is probably even higher. Rayon, however, should not be looked upon as a substitute for silk, but rather as unique fibers with distinct and valuable properties of their own. These fibers may be used alone in fabrics; in conjunction with cotton to furnish an attractive decorative effect; or with wool to produce pleasing new fabrics of lowered cost. New applications are constantly being found. In 1910 the production of rayon in the whole world was only about 10,000,000 pounds, and none was being made in the United States. In 1928, on the other hand, 100,000,000 pounds were turned out in the United States alone, and in 1931 the production here amounted to about 144,000,000 pounds, the figure for 1932 being 10 percent less than for 1931.⁴

In spite of the rapid developments of the last few years, it is doubtful whether the real significance of these new fibers has yet been visualized by anyone. When first produced in this country 20 years ago they lacked strength and resistance to water but improvement in these and other directions has been constant. A special type of rayon fiber has been developed which rivals silk in appearance and strength even when wet, though certain other characteristics have thus far prevented its wide introduction into the textile industry.

Even beyond rayon, cellulose is continuing to be a powerful aid in making possible new developments which are changing the whole trend of civilization. For the airplane, as in earlier forms of transportation, cellulose was the first material to which man turned. The framework and propeller were made of wood, the wings were covered with cellulose in the form of linen or cotton fabrics, and these in turn coated with cellulose nitrate or cellulose acetate varnishes to

⁴ It is of interest to note that rayon production in 1933 amounted to 208,530,000 pounds, an increase of 60 percent over the preceding year.

render them taut. Whatever the future of the metal airplane, the availability of cellulose and its remarkable adaptability have helped markedly in the progress of aviation.

The merchandising of packaged articles is today dependent to a very large extent upon cellulose. The large container or carton is made from paper board as are the smaller boxes which hold the individual units of merchandise. To increase the appeal to the eye, the chemist in recent years has furnished transparent sheets of Cellophane and Sylphwrap. The chemistry involved in the manufacture of this material is the same as that of the viscose process for manufacturing artificial silk, but instead of extruding the cellulosic solution through minute orifices it is forced through a long narrow slot into a hardening bath.

Another new use for a cellulose derivative is in the manufacture of shoes. In this novel process all sewing or nailing of the shoe is eliminated and the shoes are literally stuck together. The cement used is a specially compounded cellulose nitrate cement with unusually rapid sticking qualities. When the process was first used in the United States in 1928 the soles had to be held in contact with the uppers for 30 minutes. At the present time the process has been so perfected that it is now only necessary to hold the two parts together for 50 seconds. The process is so rapid that a single operator in 8 hours and 15 minutes applied soles to 1,580 pairs of shoes. The indications are that over 50,000 pairs of shoes will be made by this method in the United States in 1933.

In this new age cellulose has taken its place as a great chemical raw material, and with increasing knowledge its importance is bound to be enhanced. Technical literature and patent indices are recording at an increasing rate new chemical derivatives of cellulose, many of which may reasonably be expected to appear in industry within the next 5 or 6 years. Already cellulose ethers are available, some of which have a very unusual resistance to both acid and alkaline solutions. Reports are also being heard with increasing frequency of new mixed esters with greatly improved properties. It is only the complex chemical character of cellulose that has so long delayed its utilization as a raw material for chemical transformation, but as the nature of the cellulose molecule continues to be elucidated a material of which so large a supply is potentially available will surely find useful application in increasing quantities.

THE VARIETY IN TIDES¹

By H. A. MARMER

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The usual explanation of the tide in textbooks of physical geography or astronomy makes of it a simple phenomenon. It is shown that the gravitational attraction of sun and moon on the earth gives rise to forces which move the waters of the sea relative to the solid earth. It is further shown that these forces have different periods, but that the predominant ones have a period of about half a day; therefore there are two high waters and two low waters in a day. And finally it is shown that the moon plays the leading role in bringing about the tide, for the tide-producing power of a heavenly body varies directly as its mass and inversely as the cube of its distance from the earth.

On the bases of these general considerations, numerous features of the tide can be explained. Thus, at the times of new and full moon, when the tide-producing forces of sun and moon are in the same phase, the tides are greater than usual, while at the times of the moon's quadratures the tides are less than usual. In the same way, when the moon is in perigee, or nearest the earth, greater tides result than when the moon is in apogee or farthest from the earth. To be sure, it is known that the tides at different places vary in time, in range, and in other features. But these differences are ascribed to modifications brought about by local hydrographic features. And thus the whole phenomenon is seemingly reduced to simple terms.

To the navigator who is familiar with the Seven Seas, however, this very much oversimplifies the subject. For he finds that the tides at different places vary not only in time and in range, but also in character of rise and fall. Quite apart from differences in time and in range, which may be regarded as merely differences in degree, it is found that tides present striking differences in kind. There is, in fact, an almost bewildering variety in tides.

Take for example the actual records of the rise and fall of the tide at three such well-known places as Norfolk, Va., Pensacola,

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Fla., and San Francisco, Calif., for the last 4 days of May 1931. These are shown in figure 1, the horizontal line associated with each tide curve representing the undisturbed or mean level of the sea. At Norfolk, it is seen, there are two high and two low waters in a day, morning and afternoon tides differing but little, and the high

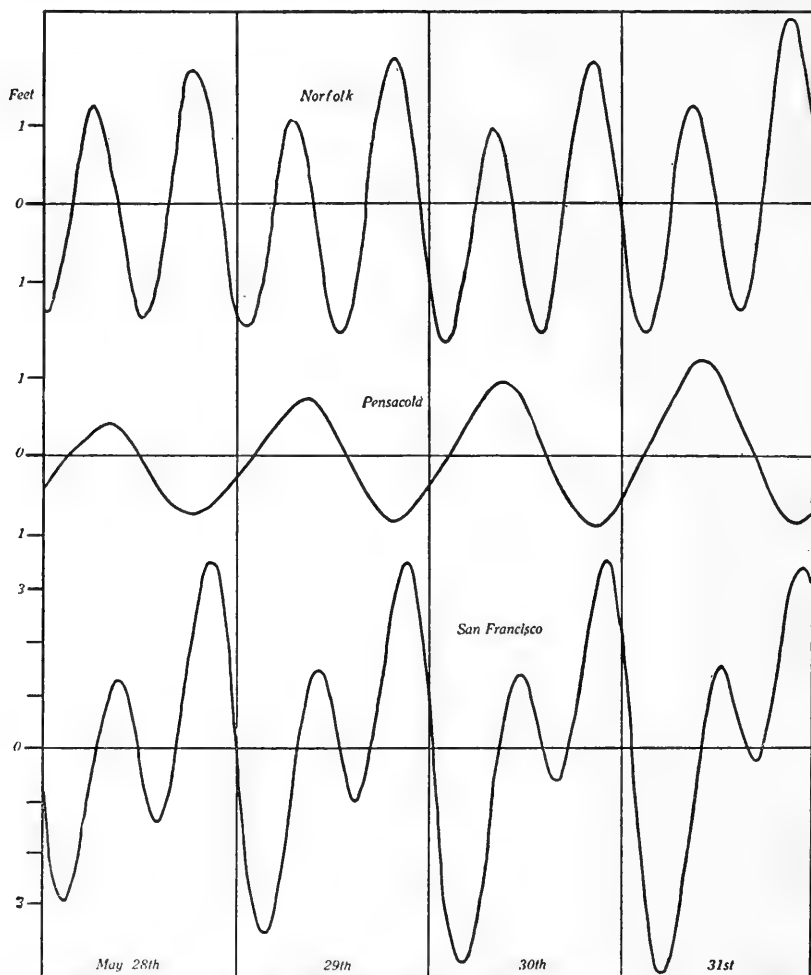


FIGURE 1.—Tide curves, Norfolk, Pensacola, and San Francisco, May 28–31, 1931.

waters rising approximately the same distance above sea level as the low waters fall below it. At Pensacola, on the same days, there were but one high and one low water each day. And at San Francisco, while there were two high and two low waters each day, the morning tides differed very considerably from the afternoon tides.

It must be emphasized that the differences in the tides at the three places shown in figure 1 are in no way due to the disturbing

effects of wind or weather. Heavy winds and rapid variations in barometric pressure do bring about very marked changes in the rise and fall of the tide. But the last 4 days of May 1931 were purposely chosen because weather conditions then were relatively uniform. The features exhibited by the tides shown in figure 1 are characteristic features of the tide at the three places.

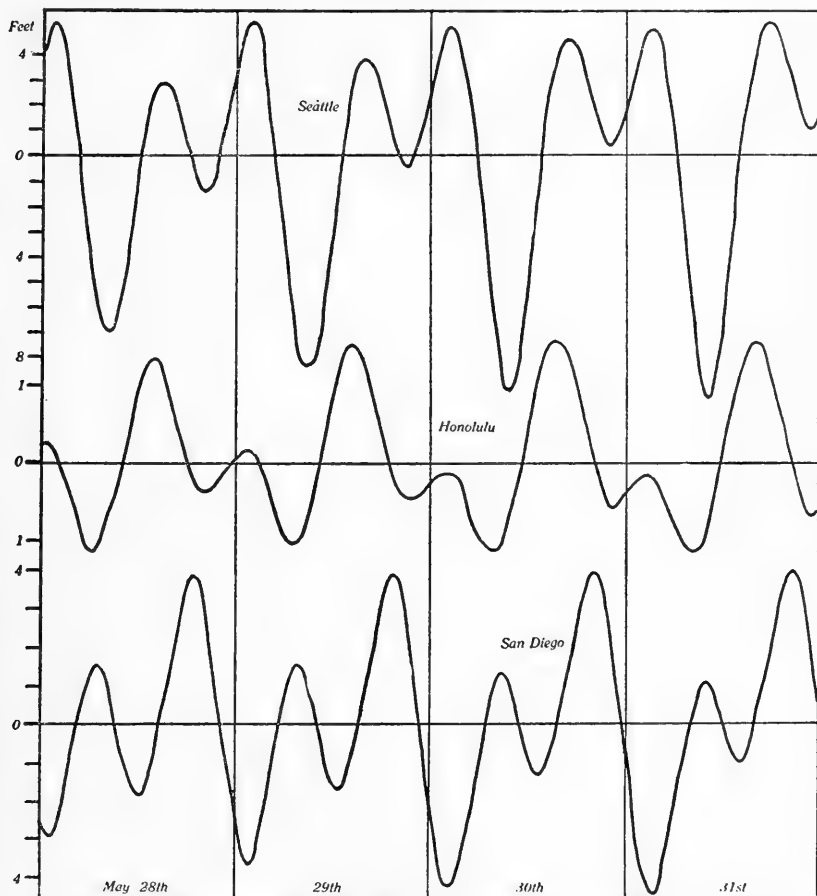


FIGURE 2.—Tide curves, Seattle, Honolulu, and San Diego, May 28–31, 1931.

If we go to other places we find yet other varieties of tides. In figure 2 are shown the actual records of the tide for the same 4 days of May 1931 at Seattle, Wash., Honolulu, Hawaii, and San Diego, Calif. At each of these places it is seen that there are 2 high and 2 low waters in a day. At Seattle, however, morning and afternoon high waters do not differ much, while the morning and afternoon low waters differ strikingly. On the last day shown in figure 2 the afternoon low water was 10.5 feet higher than the

morning low water. At Honolulu, conditions are the exact reverse of those at Seattle, for at the former place the differences between morning and afternoon tides are exhibited principally by the high waters. It is of interest to note, too, that, during the last 2 days, the afternoon low waters at Seattle did not fall as low as sea level, while at Honolulu the morning high waters did not rise as high as sea level.

In contrast with conditions at Seattle and Honolulu, the tide curve for San Diego shows the differences between morning and afternoon tides to be exhibited in approximately equal degree by

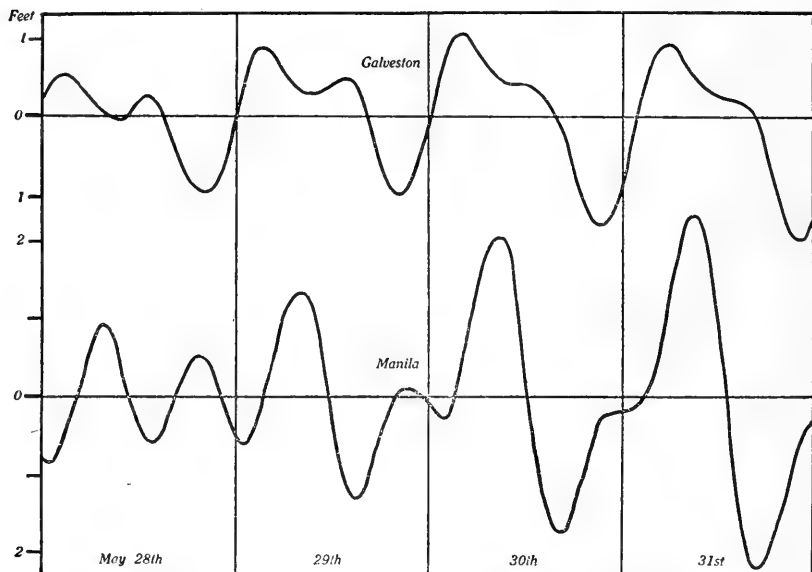


FIGURE 3.—Tide curves, Galveston and Manila, May 28-31.

both high and low waters. The tide curve for San Diego looks much like that at San Francisco shown in the bottom diagram of figure 1. At the latter place, however, it is seen that there is a greater difference between the two low waters of a day than between the high waters.

Now it is a well-known fact that at any place the tide has local features with regard to times of high and low water, range of tide, or characteristics of rise and fall which distinguish it from the tide at other places. But in the tides represented in figures 1 and 2, time and range were disregarded, and the features considered were not minor differences but characteristics of a fundamental nature. In other words the tides at these places constitute distinct varieties.

The varieties of tides considered above do not, however, exhaust the variety in tides. In figure 3 are shown the records of the tides at Galveston, Tex., and at Manila, P. I., for the same 4 days of May 1931. At Galveston, for the first 2 days, there are 2 high and 2 low waters each day; but for the last 2 days, there are but 1 high and 1 low water a day. A characteristic feature of the tide during these last 2 days is the long stand of the tide which begins about 4 hours after high water, when for a period of about 3 or 4 hours the tide changes but little in height. At Manila, there is a somewhat similar state of affairs; but whereas the stand of the tide here takes place on the rising tide, at Galveston it takes place on the falling tide. Furthermore, the stand of the tide at Galveston occurs above sea level, while at Manila it takes place below sea level.

On investigation it will be found that most tides can be referred to one or another of the varieties discussed above. Furthermore, it can be shown that these different varieties arise from different combinations of two primary constituent tides. In developing the tide-producing forces arising from the attraction of sun and moon, it is found that these forces have different periods, the principal ones being those having a period of a day and of half a day, respectively. The daily tide-producing forces give rise to a tidal constituent having a period of a day, and the semidaily forces give rise to a tidal constituent having a period of half a day. And it is the varying combinations of these two constituent tides that give rise to the different varieties discussed. An example will make this clear.

Suppose that in a certain sea the tide-producing forces give rise to daily and semidaily tides with different ranges. If the semidaily constituent has much the greater range, it is clear that within that sea the tide will be much like that at Norfolk, morning and afternoon tides differing but little, and the tide will be of the semidaily type. If the range of the daily constituent is much the larger the tide will be like that at Pensacola with but one high and one low water in a day, or of the daily type.

But suppose that the two constituent tides have the same range, what is the character of the resultant tide? The rise and fall of each of these constituent tides may be represented as in figure 4, the semidaily constituent by the dotted curve and the daily constituent by the dashed curve. The height of the resultant tide at any moment is then clearly the sum of the heights of the constituent tides at that moment. In figure 4 the resultant tide is indicated by the heavy full-line curve.

Now the two constituent tides may combine in various ways in regard to time. In figure 4 three cases are considered. In the upper

diagram the two constituent tides have such time relations that their low waters occur at the same time. The resultant tide in this case resembles the tide at Seattle, the differences between morning and afternoon tides being wholly in the low waters. The middle diagram represents the case in which the high waters of the two constituent tides occur at the same time, and now the resultant tide resembles that at Honolulu, the differences between morning and afternoon tides being exhibited wholly in the high waters. Finally, the lower

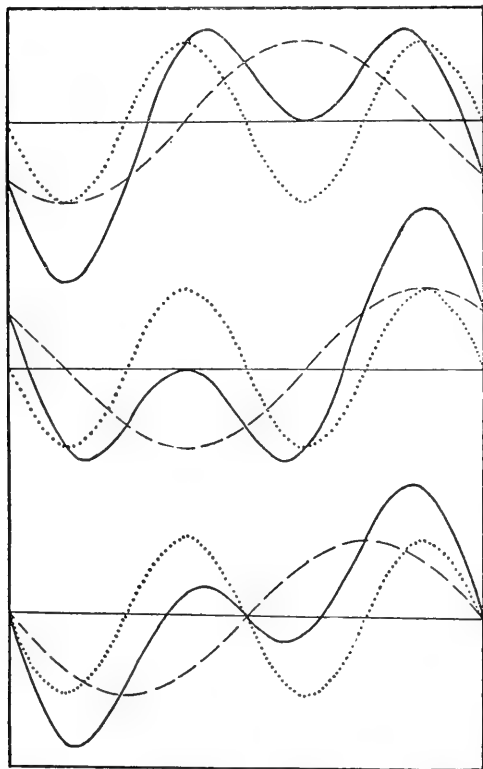


FIGURE 4.—Combination of daily and semidaily constituent tides

diagram represents the conditions resulting when the two constituent tides are at sea level at the same time. Now the resultant tide resembles that at San Diego, the differences in the morning and afternoon tides being exhibited in equal degree by both high and low waters.

It appears, therefore, that the varieties of tides represented by such tides as at Seattle, Honolulu, and San Diego arise from a mixture of daily and semidaily tides of approximately equal range. Such tides are known as the mixed type.

Tides in which a stand occurs, as at Galveston and Manila, can be shown to arise from a combination of a daily and a semidaily constituent in which

the former has twice the range of the latter. If in the case represented by the lower diagram of figure 4, we take the range of the daily constituent twice that of the semidaily, it is found that the resultant tide will have but one high and one low water with a stand on the rising tide. If we take the two constituents such that are at sea level at the same instant, but both rising instead of falling, as in figure 4, the stand will occur on the falling tide. And it is to be noted that both the daily and semidaily tide-producing forces vary in intensity from day to day, the former being greatest when the

moon is at its semimonthly maximum north or south declination, and the latter being greatest when the moon is over the Equator. It is in this varying relation of the magnitudes of the daily and semidaily tide-producing forces through a fortnight that we find explanation of tides which part of the time are of the mixed type and part of the time of the daily type.

The strikingly different characteristics of the varieties of tides discussed above have been traced back to the combination of daily and semidaily constituent tides of different times and ranges. The question that immediately arises is, why do the waters of the sea in different places respond differently to the tide-producing forces of sun and moon? For these tide-producing forces are distributed in a regular manner over the entire earth.

To answer this question it is necessary to consider the physics of the movement of bodies of water under the impulse of periodic forces. Briefly, it may be stated that a body of water has a natural period of oscillation which depends on the length and depth of the body of water. Furthermore, when disturbed by periodic forces that tend to upset its equilibrium, a body of water will respond best to that force the period of which most closely approximates to its natural period of oscillation.

The principal tide-producing forces of sun and moon, as has been noted before, are those having periods of half a day and a day, respectively. As these tide-producing forces sweep over the earth they put into oscillation the waters of the various oceanic basins. But the response of any given oceanic basin to these forces depends on the natural period of oscillation, which period is determined by the length and depth of the basin. Those basins whose natural periods of oscillation approximate to half a day respond best to the semidaily tide-producing forces; hence the semidaily constituent of the tide will predominate and the tide in these basins will be of the semidaily type. Those bodies of water whose natural periods of oscillation approximate to a day will respond best to the daily tide-producing forces and thus give rise to daily tides. At the same time, those bodies of water, the natural periods of oscillation of which approximate to the daily forces as closely as to the semidaily forces, will respond in approximately equal degree to both kinds of tide-producing forces and hence give rise to mixed tides.

The varieties of tides described above are those most frequently met with in the large world ports. There are places, however, where local hydrographic features give rise to peculiarities not found at other places. Along the open sea and in coastal bodies of water, the durations of rise and fall of tide are approximately equal. This gives the rising and falling portions of the tide curve a symmetrical

appearance with regard to high or low water. In the upper reaches of tidal rivers, however, especially where there is considerable fresh-water discharge, this is not the case. Thus at Albany, near the head of tide water on the Hudson River, at times of freshets the tide may rise for 3 or 4 hours and fall for 8 or 9 hours. This gives the tide curve in such rivers a characteristic appearance, the rise being represented by a short steep line, while the fall is represented by a longer gently-sloping line.

This feature in river tides is obviously due to the resistance of the river bottom and banks to the upstream progress of the tide. Furthermore, the drainage waters which find their way into a river give rise to a current that tends to flow downstream constantly. This acts as an added element of resistance to the progress of the tide upstream. And thus the duration of rise of tide is shortened, while the duration of fall is correspondingly lengthened.

In certain rivers the tide during a portion of its rise comes as a wall of water several feet in height. This phenomenon is known as a bore and is found to occur in the upper regions of tidal rivers having large ranges of tide, the channels of which are obstructed by bars and mud flats. This may be considered as the limiting case of river tides, in which the steepness of the rising tide becomes so great as to become vertical during a part of the rise. In North America the best known bore is that occurring in the Petitcodiac River in Canada. The largest bore is probably that found in the Tsientang, a Chinese river which empties into the China Sea. In this river the bore comes as a wall of water 10 feet or more in height, its front a sloping cascade of bubbling foam.

Throughout the world, with but rare exception, the sovereignty of the moon over the tide is clearly exhibited by the retardation in the times of high and low water by about 50 minutes each day. Thus in figure 1 it is seen that the first high water of May 28 at Norfolk occurred at 6 o'clock and that each day thereafter it came about an hour later. The other high water and also the low waters are seen to have occurred approximately an hour later each day. And at Seattle, with a totally different kind of tide, a similar retardation in the times of high and low water is seen to have occurred. This merely confirms the old adage that "the tide follows the moon." For the transit of the moon over any place occurs each day later by 50 minutes, on the average.

There are some places, however, where the tide appears to follow the sun rather than the moon. That is, instead of coming later each day by about 50 minutes, the tide comes to high and low water at about the same time day after day. Thus at Tahiti in the Society Islands, it has been known for many years that high water generally comes about noon and midnight and low water about 6 a. m. and

6 p. m. In fact, it appears that the natives use the same word for midnight as for high water. At Tahiti, therefore, the tide is solar rather than lunar.

The range of the tide at Tahiti is small, less than a foot on the average. A better example of the solar type of tide has recently come to light at Tuesday Island, a small island in Torres Strait, lying about 15 miles northwesterly from the northern point of the

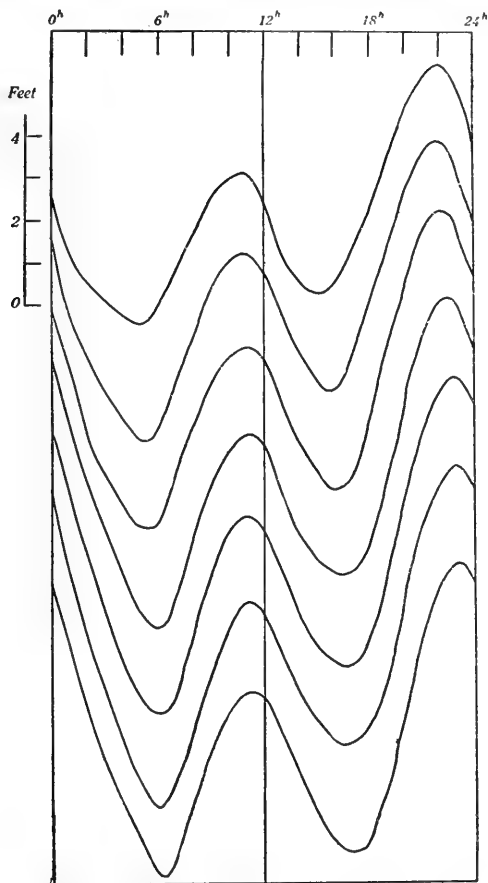


FIGURE 5.—Tide curves, Tuesday Island, Sept. 10-16, 1925.

Australian mainland. Here the range of the tide averages nearly 5 feet. The peculiar behavior of the tide here with regard to time is clearly brought out if the tide curves for a number of days are arranged in column, as in figure 5, which represents the tide curves for each day of the week beginning September 10, 1925.

It will be noted that the high and low waters in this figure fall practically in a vertical line; which means that instead of coming later each day by about 50 minutes, which is the state of affairs at

most places in the world, the tide here comes about the same time day after day. That this is not a general feature of the tides in the South Pacific Ocean is evident from a comparison with the tide curves for Apia, Samoa, for the same week, which are shown in figure 6. It will be noted that here there is a distinct shift to the right in regard to the times of high and low water in following down the curves.

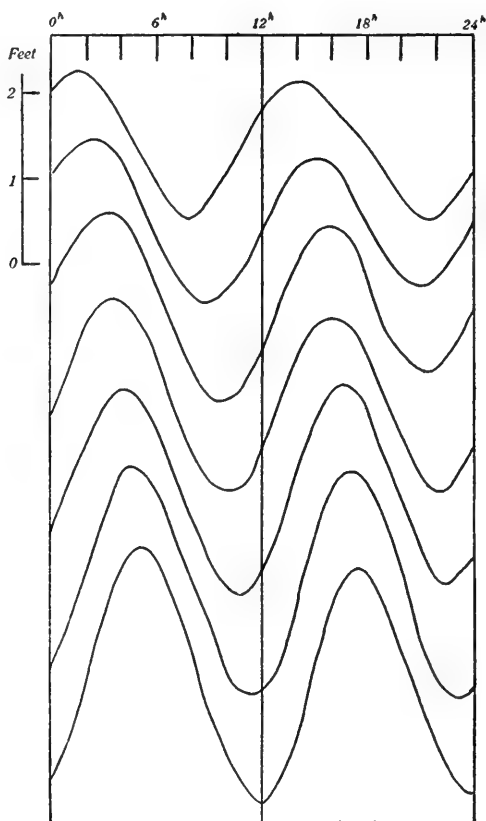


FIGURE 6.—Tide curves, Apia, Sept. 10-16, 1925.

The mathematical process of harmonic analysis permits the tide at any place to be resolved into its simple constituent tides. At Apia the principal lunar constituent has a range of 2.5 feet, while the principal solar constituent has a range of 0.6 foot. Hence the tide here follows the moon. At Tuesday Island, the principal lunar and solar constituents both have the same range of 3.1 feet. Hence here the tide is no longer predominantly lunar but as much solar as lunar.

The answer to the question as to why the tide at some places is governed by the sun rather than the moon is again found in the physical characteristics of the various oceanic basins and seas. Where the

conditions are such as to restrict the response to the lunar tide-producing forces but not the response to the solar tide-producing forces, the latter become the more prominent and give rise to solar tides.

An interesting form of tide is found at Jolo, in the Sulu Archipelago, P. I. Here the high waters follow the moon but the low waters appear to follow the sun. The tide curves for the week beginning September 10, 1925, at Jolo are shown in figure 7. The tide

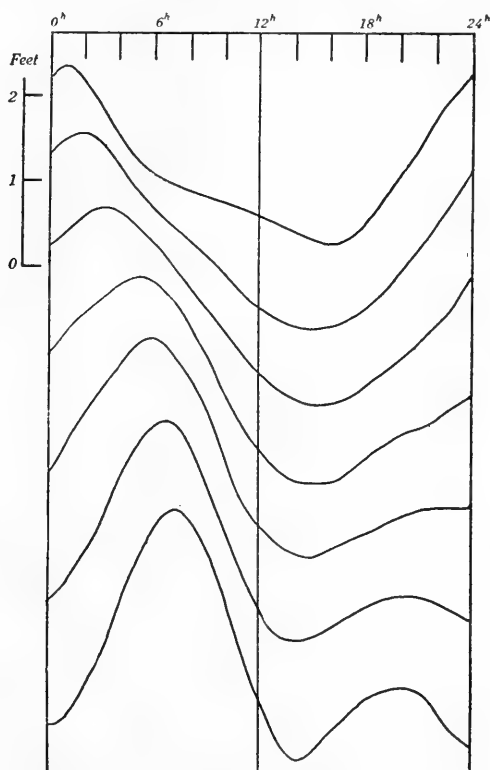


FIGURE 7.—Tide curves, Jolo, Sept. 10-16, 1925.

here is complicated by the fact that for part of the month there are two high and two low waters in a day, while at other times there is but one high and one low water. It is seen, however, that the high waters exhibit the distinct shift to the right characteristic of lunar tides, while the low waters lie almost perpendicularly under each other.

Because of the profound influence of the hydrographic features of a body of water on the movement of the waters in response to the tide-producing forces, various other peculiarities of the tide are found at different places. But the varieties discussed above constitute the more important and most generally found varieties of the tide.

MODERN SEISMOLOGY¹

By F. J. SCEASE

Kew Observatory

INTRODUCTION

As the main branches of science expand and overlap each other, new subdivisions become recognized. Geophysics is a conspicuous instance of such subdivision, and it is one in which there has been a considerable development of interest in recent years. In view of this development the National Research Council at Washington has thought it desirable to prepare a series of bulletins on the physics of the earth with the object of giving scientists who have no special knowledge of the subject some idea of the present position of geophysics and its main problems. Several bulletins of this series have already appeared, the most recent being one on seismology.² The authors of this volume, viz, J. B. Macelwane, H. O. Wood, H. F. Reid, J. A. Anderson, and P. Byerly, are all well-known seismologists, and their symposium forms a clear and comprehensive survey, mainly from the physical standpoint, of modern ideas on the subject. In the present article it is not intended to give more than a brief outline of these ideas; those readers who feel encouraged to enter more deeply into the subject will find the National Research Council's bulletin a useful guide to further study of the physics of earthquakes.

THE GROWTH OF MODERN SEISMOLOGY

Before the latter part of the last century seismology did not offer a very attractive field to scientific men, mainly because the data then available were crude and unreliable. That the subject has now taken its place as a quantitative physical science is due, in no small measure, to the pioneer work of John Milne, whose

¹ Reprinted by permission, with slight alterations, from *Science Progress*, no. 113, July 1934, published by Edward Arnold & Co., London.

² Bulletin of the National Research Council, no. 90. *Physics of the Earth*, vol. 6; *Seismology*. Pp. viii+233 (Washington, D. C.: National Academy of Sciences, 1933). Paper, \$2; cloth, \$2.50.

interest in the subject was roused by his experience of earthquakes during the period 1876 to 1895 when he was professor of mining and mineralogy in Japan. The subject was also taken up by workers in Germany and Italy about the same time, and very soon various types of apparatus were devised to record earthquakes at great distances. On his return to England in 1895 Milne set up his own earthquake observatory at Shide in the Isle of Wight, and in 1897 he inaugurated a scheme whereby recording instruments were installed at a number of stations in various parts of the globe. The observatory at Shide became the central office of a world-wide seismic survey, and the comparative data thus obtained soon laid bare the main facts regarding the propagation of earth tremors through and round the world. A great advance was made at the beginning of the present century, when Wiechert and his pupils at Göttingen took up the question of the interpretation of seismograms both from the observational and the theoretical side, and showed how the results lead to a knowledge of the physical properties of the earth. When Milne died in 1913, the organization which he had built up passed into the hands of the late Prof. H. H. Turner, who had shared Milne's enthusiasm in the work for many years. In addition to his other duties Turner found time for much research in seismology, notably on earthquake periodicities and deep earthquakes, and his interest in the subject lasted right up to the last conscious minutes of his life, for the collapse which led to his death occurred while he was in the presidential chair of the International Seismological Association at the Stockholm Congress in August 1930.

Progress in seismology is dependent to a very large extent on international cooperation, and for this reason alone the subject is deserving of all the support we can give it. Since the war the number of observing stations in the world-wide network has increased nearly threefold; at the present time there are nearly 400. Practically every country in the world takes a share in the observations. The work, started by Milne and continued by Turner, of collecting data and issuing a summary of the results is still undertaken in England, at the University Observatory, Oxford, under the auspices of the British Association. In addition to the routine work of recording and measuring earthquakes a large amount of seismological research is now being done in many countries, and this is leading to an increased knowledge of the properties of the earth.

HOW EARTHQUAKES OCCUR

The earth's crust has by no means reached a stable state; it is continually undergoing deformation under the influence of stresses

which develop within it. The deformation frequently takes the form of a sudden fracture in which the energy stored up by the strain is converted into the energy of internal motion. At the surface of fracture a displacement occurs which sets up vibrations that spread throughout the earth. The majority of severe earthquakes are produced in this way; such earthquakes are said to be tectonic in origin to distinguish them from shocks caused by stresses arising from volcanic activity. The class of tectonic earthquakes is by far the larger and more important one; most of the shocks that occur in volcanic regions are small in total energy. Sometimes, however, shocks of greater violence appear to be associated with volcanic eruptions, but it is doubtful whether these earthquakes are truly volcanic in origin.

Whatever its origin, an earthquake sets up a disturbance of the ground which is communicated to other parts of the earth in the form of waves. Since the waves spread out in all directions, the motion of the ground at places distant from the origin of the shock is in general very small. With suitable recording apparatus, however, it can be detected even at the opposite end of the earth. In general, any earth movement may be considered as made up of three linear displacements along directions at right angles to each other. A fully equipped observing station therefore requires three seismographs, and the components of the displacement which these are set to record are usually the north-south, the east-west, and the vertical. Many stations, however, only record the horizontal components, since vertical seismographs are generally more troublesome to operate.

THE SEISMOGRAPH

The main principle of the seismograph may be explained briefly as follows: A body attached rigidly to the ground will undergo the same displacement as the ground itself. If, however, the attachment is not rigid there will be some relative motion between the body and the ground, and it is this relative motion which enables us to determine how the ground itself is moving. Thus the essential part of a seismograph is like a pendulum, the bob of which tends to remain stationary in space while everything to which it is attached is moving. Actually the bob does not remain stationary, because it is impossible to eliminate entirely the effect of the attachment, but in certain circumstances it is possible to make allowance for this and so obtain the true motion of the ground. The modern development of seismographs has been in the direction of providing increased magnification of the relative motion and of insuring adequate damping of the moving system. The latter is necessary, since

any undamped oscillatory system has a period of its own irrespective of the period of the vibrations which are forced upon it, and in such a case the motion recorded bears no definite relation to the true earth motion. For magnifying the movement of the pendulum mechanical lever arrangements are tending to be displaced by optical or electromagnetic methods of recording which have the advantage of eliminating friction. In some of the older types of seismographs the weight of the main mass of the pendulum often ran into hundredweights or even tons; it is now realized that such heavy systems are not necessary, and the tendency now is to go to the other extreme. The moving mass of the Wood-Anderson seismograph, for instance, weighs no more than a few grams, and whereas most other horizontal instruments use gravity as the restoring force this instrument employs the torsion of a stretched fiber. In vertical seismographs a coiled spring is generally used to control the motion of the pendulum, and the chief difficulty associated with these instruments is the effect of temperature on the elastic constants of the spring. This has been overcome to some extent by the use of elinvar alloy, but there is still plenty of room for improvement in the design of vertical seismographs. A point of very great importance in the recording of earthquakes is the accuracy of the timing of the records. There is no difficulty in getting sufficiently accurate time marks from a control clock which can be checked by wireless time signals, but unfortunately some seismograms suffer from the lack of uniformity of rotation of the recording drums.

EARTHQUAKE WAVES

The record of a strong earthquake obtained on a modern seismograph at fairly large distances from the epicenter³ usually presents a characteristic appearance. Three distinct portions can be recognized; the first has a sharp commencement followed by rapid but irregular oscillations. After a certain interval there is a second abrupt pulse and rather larger but still irregular vibrations. In the last phase the maximum movement is reached, and it is characterized by smoother oscillations of longer period and greater amplitudes. The disturbance then gradually dies away after lasting, in many cases, for several hours. Now in the theory of elastic vibrations in a homogeneous solid it had long been known that two types of waves could be transmitted through the medium with different velocities. One of these is known as the compressional or longitudinal wave, in recognition of the fact that the displacement of the medium occurs in the direction of propagation, as in the case of sound waves.

³ The point within the earth at which the shock originates is called the focus; the epicenter is the point on the surface vertically above the focus.

The other is called the distortional or transverse wave since the displacement is at right angles to the direction of propagation, as is the case with light waves. For each type of wave the speed of propagation depends on the elastic constants and the density of the material. Seismologists are now agreed that on the seismogram of an earthquake at a fairly large distance the primary pulse, usually denoted by P, marks the arrival of the compressional wave, whilst the commencement of the second phase, denoted by S, indicates the arrival of the distortional wave. Professor Turner very appropriately described these waves as the "push" and the "shake" waves. In addition to these body waves which travel through the medium, there is another type of wave which can travel along the surface in much the same way as water waves are propagated. These surface waves were discovered by Lord Rayleigh and are usually named after him. They play an important part in the third portion of the seismogram; the commencement of this portion is usually called the long wave or L phase.

With the improvement of instrumental records it was soon found that the times of travel of the P and S waves gave a smooth curve when plotted against the distance from the epicenter. In 1907 Wiechert and Zoeppritz constructed travel-time graphs from a careful examination of the records of three well-defined earthquakes, and the tables derived by Turner from these graphs have served as a basis for all important seismological work until quite recently. These tables have been used, for example, in the determination of epicenters and times of origin of earthquakes which are published regularly in the International Seismological Summary. From the time interval between the P and the S phases at any station both the epicentral distance and the time of origin can be estimated by means of the tables, and if the time intervals for three well-distributed stations are known the position of the epicenter can be located. A rough estimate of the position of the epicenter can often be obtained at a single station provided that good records of all three components are available, for a comparison of the amplitudes of the components of the initial longitudinal pulse indicates the direction from which the wave has arrived; this information together with an estimate of the distance obtained from the S-P interval gives the locality of the epicenter.

It has been realized for some years now that the Zoeppritz-Turner tables have appreciable errors, amounting at some distances to 20 seconds, and much work has been done recently on the construction of more accurate tables. H. Jeffreys and K. E. Bullen have obtained revised times of travel of P and S from a statistical analysis of data taken from a large number of the most fully observed earthquakes treated in the International Seismological Summary;

these average times are probably accurate to within 1 or 2 seconds, but a point that remains doubtful is to what focal depth they correspond. The next step is to compare the average times with the data obtained from detailed studies of the records of individual earthquakes; in this way local variations in the velocities of the waves and differences in the structure of the earth may be revealed.

WAVES IN THE EARTH'S CRUST

Some information as to the constitution of the upper layers of the earth's crust in certain continental regions has been obtained from the study of near earthquakes. The records of shocks at distances of less than about 800 kilometers often show not only the normal P and S pulses, but also other pairs of compressional and distortional waves that have traveled in the crustal layers. According to Jeffreys' interpretation of these waves there are at least 3, perhaps 5, layers concerned: the upper layer of granite (which is generally overlaid by 1 or 2 kilometers of sedimentary material) is about 10 kilometers thick; the intermediate layers between the granite and the ultrabasic rock (which transmits the normal waves) are together about 20 kilometers thick.

The existence of the crustal layers not only accounts for the phenomena of near earthquakes, but also goes a long way toward explaining certain observed characteristics of the surface waves which are not in agreement with the theory of waves on a homogeneous solid. For instance, the simple theory does not account for the long train of waves which characterizes the L phase; the velocity of Rayleigh waves in a homogeneous earth is independent of the wave length and so the Rayleigh phase should consist of a single disturbance instead of a long train. In a layered crust, however, we find a qualitative explanation in the effect of dispersion (i. e., the dependence of the velocity of a wave on its period), which converts an impulse into a series of approximately harmonic waves; the amplitude of Rayleigh waves dies down with depth in a distance proportional to the wave length, so the short waves are confined to the upper layer, in which the velocity is least, while the longer waves extend into the lower layer where the velocity is greater. A quantitative analysis of the Rayleigh waves is not at present available because the variation of their velocity with wave length has not yet been worked out. A further difference between the simple theory and the observed facts is that the motion in the theoretical Rayleigh wave is wholly in the plane containing the vertical and the direction of propagation, whereas the actual motion in the long-wave phase of an earthquake has a strong component at right angles to the direction of propagation. This difficulty was removed in 1911 by

Love, who showed that another type of surface wave, in which the displacement is horizontal and perpendicular to the direction of propagation, can be transmitted in a layer of finite thickness resting on a deep solid layer; it is necessary that the velocity of distortional waves should be greater in the lower layer. Love waves, as they are called, are equivalent to horizontally polarized S waves reflected up and down within the upper layer in much the same way as light waves in a slab of glass, the upper face of which is a perfect reflector and the lower face bounded by material of higher refractive index. Since the displacement in these waves is wholly horizontal, they do not appear on seismograms of the vertical component. The study of Love waves has enabled Stoneley and others to obtain estimates of the thickness of the continental upper layers; their results are in reasonable agreement with those given by near earthquakes. Seismological evidence as to the structure of the crust under the oceans is not so abundant, but the fact that surface waves travel appreciably faster along oceanic paths than along continental paths indicates that the granitic layer is thin or absent under the oceans; this fits in with geological evidence which shows that granitic rocks are comparatively rare on oceanic islands.

WAVES IN THE INTERIOR OF THE EARTH

The waves of near earthquakes do not penetrate very deeply into the earth and the information which they yield is confined to the upper layers. The waves of distant earthquakes, on the other hand, reach great depths, and they enable us to obtain some knowledge of the constitution of the interior of the earth. In the first place, the slopes of the time-distance curves of P and S indicate that the velocities of these waves, which are about 8 and 4.5 kilometers per second respectively just below the crust, increase with depth to about 13 and 7 kilometers per second at 2,900 kilometers below the surface. Since the velocity depends directly on the elasticity and inversely as the density of the material through which the wave is propagated, it appears that the elasticity increases more rapidly with depth than the density. The rate of change of velocity is not uniform all the way down to 2,900 kilometers however; the latest time-distance tables of Jeffreys and Bullen indicate that there is a rapid increase of velocity at a depth of about 400 kilometers for which there is at present no satisfactory explanation. Further information about the rate of change of velocity with depth has been obtained by studying the variation of the amplitudes of recorded pulses with distance; by this method Gutenberg inferred that a discontinuity occurs at a depth of about 1,200 kilometers.

The waves which penetrate to a depth of 2,900 kilometers travel to a distance of about 10,000 kilometers. When this distance is exceeded the ordinary P and S waves become very feeble and difficult to identify, but at about 16,000 kilometers a new compressional wave appears and remains recognizable to the antipodes of the epicenter. The delay of this wave, compared with the ordinary P, shows that the velocity, instead of continuing to increase with depth, must suffer a decrease at some considerable depth. This led Oldham to suggest that at this depth, which is now known to be about 2,900 kilometers, there is a discontinuity which forms the boundary of a central core of the earth. The core acts like a lens and waves which are transmitted through it undergo refraction at the boundary. The effect is to produce a shadow zone in which neither the waves which just miss the core nor those which are refracted by the core appear; thus on seismograms recorded at distances between 10,000 and 16,000 kilometers neither the ordinary direct compressional wave nor the compressional wave which has traveled through the core can be recognized. Another point of very great importance is that the core is apparently unable to transmit distortional waves; the S waves which strike the core are transformed on refraction into compressional waves which can change back to the S type when the boundary is crossed the second time.⁴ Since for the transmission of distortional waves a material possessing some rigidity is necessary, it is inferred that the central core of the earth is nonrigid and is therefore composed of material in the liquid state. On the seismogram of a distant earthquake a number of phases can usually be recognized in addition to the P and S waves or the waves transmitted directly through the core. Some of these phases are due to reflection of waves at or near the earth's surface. Reflection can also take place at the core boundary, and the fact that such reflected waves produce sharp pulses on the records shows that the transition between the solid shell and the liquid core must be a rapid one.

DEEP EARTHQUAKES

Although there is still some difficulty in deciding what figure we may take as the average depth of focus of normal earthquakes it is almost certain that the majority of shocks originate at depths of less than 50 kilometers below the surface. That some earthquakes occur at much greater depths than this, however, was suggested by the late Professor Turner, who noticed that for some shocks the

⁴ Some investigators have claimed that pulses representing distortional waves through the core can be observed in the seismograms of distant earthquakes. A correct interpretation of such records is often very difficult, however, owing to their complexity. It seems clear that generally no prominent waves of this type occur.

times of travel of the compressional waves to stations nearly antipodal to the epicenter were consistently abnormal; if the focus is deeper than normal the waves arrive at distant stations earlier than the normal time. For some years, however, Turner's hypothesis of deep focus was not generally accepted because he also maintained the possibility of abnormally shallow focus to account for a few shocks in which the compressional wave arrived late at antipodal stations, and this implied that the normal focal depth is as great as 250 kilometers. Independent evidence of the occurrence of deep focus earthquakes was obtained by Wadati, who noticed that some Japanese shocks showed an abnormal distribution of intensity over the region in which they could be felt and that the time intervals between the S and P phases were abnormally large near the epicenter. The question was placed beyond doubt by the present writer, who identified on the records of supposed deep-focus earthquakes certain phases which could only be explained as reflections of P and S waves near the epicenter; such reflections may occur in normal earthquakes, but it is only when the focus is deep that these additional phases can be separated from the direct pulses. Another characteristic of deep-focus earthquakes, recognized by Stoneley and others, is that the surface waves are very weakly developed; this is in agreement with theory which shows that the amplitudes of these waves should fall off rapidly with depth. The more recent work on this class of shock is mainly concerned with the construction of time-distance curves applicable to various focal depths. The preliminary curves prepared by the writer were obtained by applying appropriate corrections for the effect of abnormal depth to the Zoeppritz-Turner tables for normal earthquakes, and they therefore suffered from the errors which were known to exist in these tables; improved curves have been obtained from detailed studies of the records of individual shocks. The occurrence of earthquakes at such depths as 500 kilometers, equivalent to nearly a tenth of the earth's radius, is of great importance, for it implies the existence of materials of great strength at these depths. It is not definitely known what is the significance of the observations which led Turner to attribute abnormally high foci to certain earthquakes, but it is probable that the apparent anomalies were due to certain phases being wrongly identified on the records.

EARTHQUAKE PERIODICITIES

Although the primary causes of earthquakes lie within the earth, it is quite possible that the actual time of occurrence of a shock is determined by external factors. As a result of the gradual development of stresses in the earth's crust dislocation has to occur sooner or later, and the extra impulse which is sufficient to start the break

may conceivably be brought about by secondary causes outside the solid earth. It is not surprising, therefore, that many investigators have endeavored to trace connections between the occurrence of earthquakes and other natural phenomena. There have been numerous attempts to find periodicities and regular variations in the frequency of earthquakes, but so far the only two that appear to be well established are the solar diurnal and annual variations found by Davison. It is found that on the whole earthquakes are more frequent during the night than during the day, and more frequent in winter than in summer. A possible explanation, suggested by Davison and by Omori, is that these variations are due to the annual and diurnal changes in atmospheric pressure. The 11-year period has been examined, and it appears that in all parts of the world earthquakes are more frequent in the years of many sun spots. Davison also investigated a 19-year period, and in this case the maximum frequencies of the Northern Hemisphere correspond with the minimum frequencies of the Southern Hemisphere; the period is the same as the nutation period of the earth, and it appears probable that the strains associated with the movements of the earth's axis are factors in determining when earthquakes shall occur.

A large earthquake is usually followed by a series of after-shocks, the daily numbers of which at first decline very rapidly. In a few days, however, the frequency curve flattens out but, as was demonstrated by Omori, it shows fluctuations which occur at intervals of a few days. Davison has examined these periodicities recently and finds that they are related to the phases of the moon. The occurrence of after-shocks was also investigated by Turner, who noticed that they appeared to recur at intervals of multiples of 21 minutes; the reality of this period, however, cannot be said to be definitely established.

MICROSEISMS

Although seismology is usually considered to be concerned only with earthquakes in the ordinary sense of the word, it also includes other shakings of the earth which are not due to fractures or sudden disturbances. At nearly every seismological station the records frequently show continuous oscillatory movements known as microseisms. The oscillations are much greater in winter than in summer, and they appear to be associated in some way with atmospheric storms; in fact, in some parts of the world attempts have been made to use them as a means of forecasting the approach of stormy weather. The exact nature of the connection is still in doubt. According to one theory microseisms are due to sea waves breaking on exposed coasts, but from a recent survey of microseismic disturbance during 1 month all over the world A. W. Lee has come

to the conclusion that there is no good evidence that waves on one coast or another are directly responsible for the production of microseisms. Neither is there any satisfactory evidence that the phenomenon is due to sea waves in shallow water. There still remains the possibility that sea waves in deep water are effective, but this idea involves certain theoretical difficulties which must be cleared up before a satisfactory explanation is obtained. The effect of geological structure on microseismic disturbance has also been investigated theoretically by Lee, and it appears that the larger microseisms are to be expected where the sedimentary rocks are of greater thickness; the results of the world survey show that this conclusion is consistent with the geological evidence.

CONCLUSION

It will be realized from this brief outline that modern seismology affords an excellent illustration of the progress which can be made by the application of sound physical principles to a subject which hitherto had no claim to be recognized as a science. From the foundations so firmly laid by Milne seismology has developed in accordance with the requirements of modern investigation and has become a quantitative science well worthy of its place as a branch of geophysics. It has already thrown much new light on the properties and structure of our globe, and it provides the most hopeful means of probing the secrets of the earth's interior.

A GENERATION'S PROGRESS IN THE STUDY OF EVOLUTION¹

By EDWIN G. CONKLIN

I

If one were searching for the most inclusive subject in modern scientific research, what other topic would touch so many fields as that of evolution? In the nonliving world it includes almost everything from the evolution of atoms to that of universes; in the living world practically everything from amoeba to man, from germ cells to developed organisms, from reflexes to reason, from savagery to civilization. Almost all the work of modern science and learning could be classified under some of these fields. The small part of this vast theme which I shall touch upon in this address concerns merely some of the recent work on the methods and causes of organic evolution.

Thirty-eight years ago I, a newcomer to Philadelphia, was introduced to the American Philosophical Society as one of the speakers in a symposium on "The Factors of Organic Evolution." The symposium occurred on the evening of May 1, 1896, the speakers being Prof. Edward D. Cope, Prof. Liberty H. Bailey, of Cornell University, and myself, and since our addresses represented fairly well the methods and conclusions of students of evolution a generation ago, I will briefly state a few of their principal conclusions. Cope² maintained the Lamarckian point of view that variations are the materials of evolution and that they are caused (1) by the direct action of the environment on developed organisms (his physiogenesis), (2) by the inherited effects of use or disuse (his kintogenesis), (3) by the energy of growth forces (his bathmogenesis) and (4) by sensations or consciousness (his archaesthetism). It was characteristic of Cope and of many other naturalists of a generation ago that they assumed the existence of certain principles of evolution which

¹ Penrose Memorial Lecture, read Apr. 20, 1934. Reprinted with slight alterations, by permission, from *Proceedings American Philosophical Society*, vol. 74, no. 1, 1934.

² He declined to furnish manuscript for publication but his views were fully expressed in his book *The Primary Factors of Organic Evolution*, which had just been published.

seemed to them logically necessary, and after they had been given high-sounding names, usually of Greek derivation, these principles seemed to be well-established realities. In addition to the four principles mentioned above such terms as catagenesis, ergogenesis, emphytogenesis, mnemogenesis, statogenesis, and many others of similar sort were introduced. Such nominalism is not unknown in evolutionary speculations even at present.

On the other side I championed³ the Weismannian view that (1) acquired characters are not inherited, (2) that inherited characters must be predetermined, but not preformed, in the germ cells, and in particular in submicroscopic inheritance units, (3) that all hereditary variations are caused by the action of extrinsic forces on the germinal protoplasm, producing changes in its structure, rather than upon developed organisms, and finally (4) that the only way of breaking the deadlock between Lamarckians and Darwinians was by means of experiment. In the light of subsequent events I think I have no reason to regret my immature contribution to this symposium.

Professor Bailey's⁴ philosophy was neither strictly Lamarckian nor Darwinian, although in general it leaned to the former; it was rather *sui generis* and might be called Baileyan. He maintained that variability is the original law of organisms, that like no more produces like than unlike, but that mutability is a fundamental and normal law, while heredity or permanency is an acquired character. The organism is shaped by its environment, and nature eliminates the non-variable and favors the survival of the unlike.

This account of a long forgotten program in the history of this Society is useful merely as indicating some of the opinions and speculations regarding the causes of evolution a generation ago. There was a plethora of speculation and discussion and a paucity of proof. In what follows I must beg the indulgence of those who are thoroughly familiar with the subject while I recount some of the main points in the more recent developments in our knowledge of evolution.

II

With the beginning of the present century the study of evolution entered upon a new era. Up to the year 1900 it had been based largely upon observations and what were supposed to be logical deductions. Really students of evolution were dealing with probabilities of a higher or lower order and no certainty could be reached on such a basis. What seemed highly probable to one per-

³ Proc. Amer. Philos. Soc., vol. 35, 1896.

⁴ *Idem*.

son seemed very improbable to another. Cope accepted all the Lamarckian factors, Romanes rejected use and disuse but accepted the others, Weismann rejected all of them. The fact of evolution was accepted by practically all scientists, but the factors of evolution were largely matters of opinion, and in general persons believed what they preferred to believe. Indeed this whole subject had become so speculative that it seemed to be a field for the exercise of the imagination rather than of scientific research, and one of the eminent younger biologists, disgusted with this flood of speculation, announced, "I am done with this entire phylogeny business."

Then in 1900 Mendel's principles of heredity, which had remained unrecognized for 35 years, were rediscovered, and a new science of accurate, experimental knowledge of heredity was born and was christened "genetics" by Bateson. Almost at once many perplexing problems of heredity were solved; "prepotency" was found to be Mendelian dominance, "reversions" or "atavism" were the reappearance of Mendelian recessives, the results of hybridization were no longer unpredictable and the laws of heredity were at last in process of being discovered.

One year later (1901) De Vries published his great work on the mutations of the evening primrose, *Oenothera lamarckiana*, upon which he had been engaged for 15 years and in the course of which he observed under rigid experimental conditions among the offspring of this one species the appearance of 9 constant mutants, 3 inconstant and 1 infertile mutant, all of which differed so much from the parent form and from one another that he called them elementary species, and maintained that they furnished actual, living evidence of experimental evolution. Galton had previously (1892) expressed his belief that "sports", or sudden variations, were the real steps in the evolution of species and Bateson had published his great work on "Discontinuity in the Origin of Species" (1894), but long before this, Darwin had given it as his opinion that evolution had occurred by means of minute variations rather than by "sports", and in this he was followed by Cope and practically all other paleontologists. Consequently it was not until De Vries had actually demonstrated the sudden appearance of mutations in his cultures that this method of evolution was widely accepted. Since then mutations have been found in almost all organisms that have been carefully studied through successive generations, and in spite of occasional objections on the part of paleontologists or other naturalists who are unable to carry on breeding experiments with their materials, the mutation theory of evolution is now well established, although it is known that mutations may be small as well as great.

However, mutations are always inherited, that is, they represent changes in the germ plasm, whereas changes which first occur in developed organisms are not inherited and are called fluctuations. This is indeed the chief distinction between the old evolution of Lamarck and Darwin and the new of Weismann and De Vries; in the old, attention was fixed upon the developed organism and evolutionary changes were supposed to be first made in the adult and then by some mysterious process to be transferred to the germ cells; in the newer views of evolution changes are first wrought in the germ cells and only later appear in the developed organism.

In 1903 Johannsen found that by continued breeding and isolation of self-fertilized beans he could isolate from a so-called pure garden variety, 19 different "pure lines" and that further selection within any one of these lines was without effect. Other similar results in a large variety of plants and animals led to the conclusion that neither artificial nor natural selection could have the effect, which Darwin had postulated, in building up a species from small variations. By some this was hailed as the "death of Darwinism", or natural selection, as a factor in evolution, but it was soon seen to apply only to fluctuations and not to mutations. It is true that selection cannot create mutations but it can act upon mutations that are offered and recent work in the field of genetics has shown that it is a potent factor in evolution.

Almost coincidentally with the rediscovery of Mendelism and the establishment of the mutation theory came the discovery of the cellular basis of these phenomena in the germ cells. The work of certain European biologists had previously furnished evidence that the inheritance material is located in the nuclei of the germ cells and chiefly if not entirely in certain threads, called chromosomes, that are found in those nuclei. When egg and sperm unite in fertilization their chromosomes commingle but retain their individual identity and in the repeated divisions of the fertilized egg, which lead to the developed animal or plant, every chromosome in every nucleus splits lengthwise and its halves separate, going into the two daughter cells; this is repeated at every cell division until every cell of the developed organism has half of its chromosomes from the egg and half from the sperm. Finally when this adult organism in turn forms eggs or spermatozoa the number of chromosomes in these sex cells is reduced to half those present in all other cells. And when the chromosomes of egg and sperm unite in fertilization, the full number is again restored. Since, on the average, organisms inherit as many traits from one parent as from the other, and, since they receive an equal number of chromosomes from each parent, it seemed highly probable that the chromosomes contained the inheritance material, but at the begin-

ning of this century no one had demonstrated any genetic relationship between any particular chromosome in a germ cell and any particular developed character.

Then, about the beginning of this century Professor McClung, now at the University of Pennsylvania, found that an "odd" or "accessory" chromosome is present in the males of certain grasshoppers, and in one of the last cell divisions leading to the formation of spermatozoa this chromosome did not divide but went into one cell but not into the other and thus two kinds of spermatozoa were formed, one containing the accessory chromosome and the other lacking it. Since these two kinds were equal in numbers, and since on the average males and females are equal in numbers, McClung in 1902 suggested that this accessory chromosome was the determinant of sex.

In keeping with the predominance of men, and of male psychology, in science it was but natural that it should have been assumed that this accessory chromosome would not be found in females and that its presence in males represented the initial cause of male superiority. But alas for this pleasing fiction! Professor Wilson, of Columbia University, and Miss Stevens, of Bryn Mawr College, independently demonstrated in 1905 that there are two such chromosomes in the females of certain insects and only one, or one and a fragment of another, in males. This difference in the chromosomes of males and females was later found in many other species, including man. In short the male generally lacks certain hereditary materials which the female possesses and instead of woman being the lesser man, as Tennyson expressed it in "Locksley Hall", man was found to be in this respect the lesser woman. Thus the initial cause of sex, which had been a subject of speculation for thousands of years, was found in a difference in certain chromosomes in the two sexes.

A study of the method by which the usual number of chromosomes is reduced to half in the egg and sperm led to the discovery of the causes of Mendelian heredity. In 1901 the late Prof. T. H. Montgomery, of the University of Pennsylvania, found that chromosomes of maternal and paternal origin unite in pairs just before the last cell divisions leading to the formation of the sex cells, and in 1902 Sutton, a student of McClung's and Wilson's, discovered that corresponding chromosomes from the father and mother come together in pairs, just as corresponding fingers of the right and left hands meet when the hands are pressed together, thumb to thumb, index to index, etc., such pairing being known as synapsis. In the subsequent cell division the chromosomes of each pair separate so that each germ cell thus formed contains only one of the chromosomes of each pair, or one-half the total number. Each of the two cells formed

by this reduction division contains one set of chromosomes, like the set of fingers on one hand, but unlike the fingers which are permanently attached to the hands, the chromosomes are free to change hands so that one germ cell may contain a thumb chromosome from the father, an index from the mother, etc., while the other cell contains corresponding chromosomes from the other parent. This union of parental chromosomes into synaptic pairs and their subsequent separation in the reduction division exactly parallels the phenomena of Mendelian segregation of characters, and there is no doubt that it is the cause of Mendelian inheritance.

With these discoveries the foundations were laid for the marvelous developments of cytology in relation to genetics which have characterized the last 30 years. Thus within the first 5 years of this century were established the Mendelian law of heredity, the mutation theory of evolution, the inability of selection to build up species from fluctuations, and the chromosomal mechanisms of sex determination and heredity.

III

Upon these foundations the study of evolution has advanced with giant strides during the past 25 years. This is especially true of the correlation between mutations, or inherited variations, and the constitution of the germ cells. Indeed this correlation has given us for the first time an understanding of the mechanisms of heredity, mutation, and evolution.

Imagine the amazement and incredulity of the naturalists of a former generation, who thought of evolution only as the transformations of developed organisms under the influence of changing environments, if they could learn that today the problems of evolution center largely in the structures and functions of germ cells! And yet this is strictly and literally true. The germ cells are the only living bonds not only between generations but also between species, and they contain the physical basis not only of heredity but also of evolution.

In the microscopic chromosomes which are found in the nuclei of all cells and in the ultramicroscopic inheritance units or genes which lie in those chromosomes are found the earliest causes of heredity, sex, mutation, and evolution. In biology as also in physics and chemistry the ultimate causes of phenomena are found not in gross bodies but in their minutest constituents. What molecules and atoms and electrons are to the physicist and chemist, chromosomes and genes are to the biologist. Present problems of evolution are not how one fully developed organism is transmuted into another, for this never happens, but rather how one type of chromosome or gene is transformed into another—not so much the effect of natural selec-

tion in eliminating certain adult forms and preserving others, although this does occur, as its much greater effect in eliminating certain types of embryos, germ cells, and genotypes.

No longer do biologists discuss how adult characters can be crowded back into the egg, nor how characters acquired by an adult can be inherited, for they are almost unanimously agreed that these things never happen, but rather they investigate how changes in chromosomes and genes are produced and how these give rise to changes in the developed organism. This revolution in the study of evolution had its remote beginnings in the nineteenth century, but its most significant results are confined entirely to the present century, most of them to the past 20 years.

It is impossible in the brief time at my disposal to deal with all of the significant advances of these recent years in the study of evolution and I must of necessity select only a few for presentation. Perhaps the most significant of these discoveries relate to the causes of mutations. In general it may be said that they are caused (1) by changes in the numbers and associations of whole chromosomes, (2) changes in the composition of individual chromosomes, and (3) changes in the position and constitution of the genes themselves. De Vries did not attempt to trace the mutations of his evening primroses to the chromosomes, but other younger persons, many of them Americans, did this, and they found that the original form, *Oenothera lamarckiana*, has 14 chromosomes, whereas there are 15 chromosomes in 7 different mutants—among them *O. lata*, *O. albida*, and *O. scintillans*, while in *O. gigas* there are 28 and in *O. semigigas* 21. Since there are typically 7 chromosomes in each of the male and female sex cells of *O. lamarckiana*, it seemed probable that these mutants were produced from sex cells, some of which had more than 7 chromosomes. It sometimes happens that a synaptic pair of chromosomes fails to separate (nondisjunction) in the reduction division in which case 8 chromosomes go into one sex cell and 6 into the other. If then a sex cell having 8 chromosomes unites with one having the normal number 7, a form with 15 chromosomes results and if this additional chromosome is from a different synaptic pair in different cases it would account for the differences in those mutants each of which has 15 chromosomes. Likewise if all the synaptic pairs fail to separate, it leads to the production of a sex cell having 14 chromosomes, and if such a cell unites with a normal sex cell with 7, it produces the mutant *semigigas* with 21 chromosomes. If both male and female sex cells fail to undergo reduction each would contain 14 chromosomes, and if two such should unite it would produce the mutant *gigas* with 28 chromosomes. There are other peculiar modifications of the chromosomes of *Oenothera*,

particularly their end-to-end union in synapsis, forming rings or chains, that cannot be dealt with here.

Many such cases of supernumerary chromosomes have now been discovered in various plants. The reduced number of chromosomes is known as haploid ($1n$), the usual condition resulting from the union of two haploid sex cells is known as diploid ($2n$), that in which there is one additional chromosome is $2n+1$, etc., that in which a diploid unites with a haploid is known as triploid ($3n$), that in which two diploid cells unite is a tetraploid ($4n$), and cells with still larger numbers of chromosomes are called in general polyploids. One of the most notable of these cases of supernumerary chromosomes has been found by Blakeslee and his associates in the numerous mutants of the common jimson (or Jamestown) weed, *Datura stramonium*. Here the typical diploid number is 24, but the addition of one or another chromosome ($2n+1$) has given rise to 12 different mutants, while many other types are produced by the further addition or subtraction of chromosomes, as well as by the breaking in two of certain chromosomes and their recombinations, a phenomenon known as segmental interchange, translocation, or "crossing over."

Haploid, diploid, triploid, and tetraploid plants of one species often differ markedly in appearance, and they breed true if the chromosomes from the two parents are sufficiently alike so that they can unite in synaptic pairs before the formation of the sex cells. Many true Linnaean species are known that have their chromosomes in multiples of some basic number common to all of them and these species have probably arisen by multiplication of this basic number. For example, many species of roses, and indeed many genera of the large family *Rosaceae*, have chromosomes in multiples of 7, and in those genera where the basal number is 8 as in plums and cherries, or 17 as in apples, hawthorns, and quinces, Darlington and Moffett have shown that this unusual number has arisen from ancestral species with 7, through nondisjunction of chromosomes at the time of cell division. In wheat, oats, and barley the basal number of chromosomes is 7, while different species have multiples of this number. Different species of *Chrysanthemum* have chromosomes in multiples of 9; more than 40 species of groundsel (*Senecio*) have chromosomes in multiples of 10; seven species of docks and sorrels (*Rumex*) also have chromosomes in multiples of 10. Many other similar cases of wild species with chromosomes in multiples of some basic number could be cited. In other native species as in the genera *Viola* and *Crepis*, chromosomes may be in multiples of some basic number, or they may be that basic number plus one or two, as in some mutants of *Oenothera* and *Datura*.

Nearly a score of new species of plants, having all the characteristics of true Linnaean species, have been artificially produced by hybridization or experimental operations with consequent changes in chromosome numbers and associations. These new species are fertile *inter se*, but are sometimes sterile when crossed with either one or both of the parent species, thus fulfilling the strictest definition of true species as laid down by many systematists. Thus Goodspeed and Clausen (1925) crossed two species of tobacco plants, namely *Nicotiana glutinosa* with 12 haploid chromosomes and *N. tabacum* with 24. The first hybrid generation normally had 36 somatic chromosomes, and they were generally sterile, but one partially fertile hybrid produced second generation plants, one of which was remarkably large and robust and was found to have 72 somatic chromosomes; that is, it was a tetraploid or *gigas* form. This plant bred true but was sterile when back crossed to one of the parent species; it has been named *N. digluta* (Clausen 1928).

Another case of the production of a true synthetic species by hybridization and subsequent doubling of the number of chromosomes was described by Newton and Pellew (1929); two distinct species of primrose, *P. verticellata* and *P. floribunda* crossed and produced a sterile hybrid; this was propagated vegetatively for several years when it suddenly produced a fertile shoot by bud transformation which bore normal seeds, and from these arose a new and fertile species, *P. kewensis*, with a tetraploid number of chromosomes.

Lindstrom (1932) cut off the tops of young tomato plants of the species *Lycopersicum pimpinellifolium*, and in the callus that formed chromosome doubling took place in some of the cells, and from these cells some tetraploid sprouts arose and bore fruit and seeds. These were highly fertile and have produced plants so different from the original stock that they should be classed as a new species, especially as they are cross-sterile with the parent species.

Another new species produced by hybridization is the pink chestnut, *Aesculus carnea*, from a cross between *A. hippocastanum* and *A. pavia*, the former with 20 small chromosomes, the latter with 20 large ones, while the new species has 20 large and 20 small chromosomes, or 40 in all (Hurst, 1932).

Still more remarkable are the results of crossing distinct genera of plants such as the common radish, *Raphanus sativus*, and the cabbage, *Brassica oleracea*, each with 9 haploid chromosomes leading to the production of a new tetraploid genus *Raphanobrassica* with 36 chromosomes (Karpechenko, 1929); or the formation of a new genus *Triticale* by crossing wheat, *Triticum vulgare*, and rye, *Secale cereale* (Levitsky and Benetzkaja, 1929).

All of the preceding cases have to do with the production of new mutants or true species by changes in the numbers and asso-

ciations of whole chromosomes. A second class of mutants are caused by changes in the composition of individual chromosomes. The members of synaptic pairs of chromosomes sometimes twist round each other, break and reunite so that portions of chromosomes become interchanged; this is known as "crossing over"; or portions of a chromosome may become detached and united to another chromosome, which is known as "translocation"; such changes in the composition of chromosomes lead to many complicated mutations which, for lack of time, cannot be described here.

All changes in the numbers or constitution of chromosomes are known as chromosome mutations, or better, permutations. Another and perhaps the most important class of mutations are those caused by changes in the positions or structures of the ultramicroscopic genes which lie in the chromosomes. Such mutations have been found in almost all animals and plants that have been bred in large numbers under experimental conditions. The most used animal for these experiments is the little vinegar fly, *Drosophila melanogaster*. Indeed in the field of heredity and evolution this is the most famous animal in the world, and the man who has been the leader in its study, Prof. T. H. Morgan, has recently received the Nobel Award in recognition of the importance of his work. Scores, if not hundreds, of different workers have been engaged in the intensive study of this little gnat and they are sometimes facetiously called *Drosophilists* or modern worshippers of Beelzebub, the god of flies. The peculiar advantages of this animal for the study of heredity and mutation are: (1) the ease with which it can be kept and bred in great numbers in milk bottles, (2) the fact that a new generation can be obtained every 12 days, (3) the large number of hereditary characters that can be recognized superficially, (4) its relatively small number of chromosomes, 4 pairs, that can be readily distinguished one from another, (5) finally more than 500 mutations have been found in some 25 millions of these animals that have been studied during the past 25 years. These mutations affect every part of the fly, such as color and form of body, wings, eyes, bristles, length of life, viability, liability to disease, etc. By several ingenious methods, which time does not permit me to describe, it has been possible to locate the particular genes that have undergone mutation in particular chromosomes and even in particular regions of those chromosomes, so that chromosome maps have been constructed giving the locations of these mutant genes in the different chromosomes.⁵

⁵ Since this lecture was given, very important discoveries have been made by Painter (1934), Muller, and Bridges on giant chromosomes in the salivary gland cells of *Drosophila*. These giant chromosomes are more than 100 times as large as the usual ones and are marked by cross-bands which correspond in position to certain known genes and thus they constitute visible chromosome maps. Some mutations of *Drosophila* are evidently caused by changes in the positions of genes in relation to other genes (Muller, 1934), whereas others are caused by changes in the genes themselves.

These mutations seem to go in all possible directions, but not in all directions. Most of these mutant flies are less viable than the wild stock from which they came, and many are lethal, that is, they kill their possessor sooner or later, but a few of them are progressive. They may occur in germ cells or in somatic cells. In short, wherever there are genes these may undergo mutation. The fact that most of these mutations are degressive rather than progressive has led some persons to doubt whether they can be the materials for evolution, but it is necessary to remember that much evolution has been degressive, and the small number of progressive mutants as compared with the multitude of regressive ones teaches us at what a price progress has been bought.

IV

The nature of the changes in genes by which mutations are caused is unknown, but it seems probable that it is some kind of physical or chemical change. The fact that it may affect one gene and not another similar one that is not more than one-thousandth of a millimeter away would seem to indicate that it is not some general environmental influence. This consideration led Muller (1927) to the conclusion that it might be due to some form of radiation similar to those by which physicists knock electrons out of atoms. Consequently he subjected *Drosophila* to X-rays and found that the frequency of mutation was increased about 150 times. Some of these mutants were of the same type as were previously known, but many were new. Most of them were detrimental, and more than half of them were lethals, but some of them were carried through 50 generations without reverting. In addition to gene mutations, X-rays cause breaks and translocations in chromosomes, which in turn cause marked changes in the developed animals.

A similar increase in mutation has been caused by X-rays in the case of barley, corn, the jimson weed, a wasp, *Habrobracon*, *et al.* They have also been induced by radium and possibly by cosmic rays. But mutations are far too common and X-rays and radium far too uncommon to warrant the conclusion that mutations are generally caused by these means.

Searching for some more common cause of mutation Goldschmidt (1929) found that by heating the eggs of *Drosophila* to such a degree as to kill most of them he obtained from the survivors two new types, and Jollos reports (1930, 1931) that larvae of *Drosophila* that were subjected to a temperature of 36° C. for 15 to 23 hours produced during 8 months more than 100 mutants, while not a single one appeared in his controls. Most important of all, some of these mutations were "orthogenetic" or progressive in a definite direction, the body color, for example, increasing from "sooty" to "ebony"

during 5 or 6 generations. Thus, for the first time, he announced, a progressive series of mutations had been called forth by a common environmental factor. If this work of Jollos is confirmed, it may well be the most important discovery made as yet regarding the method and cause of evolutionary mutation. Plough and Ives (1934), who have this month [April 1934] announced the results of their repetition of the experiments of Goldschmidt and Jollos, find that six times as many mutations occur in the heated lines as in the controls, but while this proves that increased temperature is a fruitful source of mutations there is so far no confirmation that these mutations are directed. Indeed, Plough and Ives expressly deny that there is any indication of orthogenetic mutations in their experiments.

Hitherto the great objection to the mutation theory of evolution has been that mutations are so generally regressive and that they lead nowhere. The only method of meeting this objection has been to rely upon natural selection to eliminate vast numbers of useless mutations and to preserve the few useful ones and thus slowly to build up the marvelous combinations of useful adaptations that all organisms possess. But there are many indications in the living world that evolution has proceeded in certain directed lines, sometimes even farther than was useful, as for example in the enormous size of body and weight of armor of certain dinosaurs and titanotheres, and many zoologists since Eimer have insisted that "orthogenesis", or directed evolution, is a necessity. If directed mutations can be caused by some common environmental factor, as Jollos suggests, it would solve one of the major difficulties of the mutation theory. Osborn in particular has emphasized the necessity of definitely directed variations in a series of publications during the past 40 years, the last of which has just been published (1934). He originally called this principle "definite variations" and later "rectigradations." More recently he has stressed the necessity not only of directed mutations but, much more, of useful and progressive mutations in any explanation of evolution. This principle of the origin of the fittest, as contrasted with the survival of the fittest, he calls "aristogenesis" (1933, 1934).

Goldschmidt has recently (1933) emphasized the importance of certain embryological processes in evolution. He concludes that genes control development partly by influencing the velocities of certain reactions, and he suggests that by changing the differential growth rate at an early stage a perfectly new evolutionary line could be started. This suggests a speculation which I advanced before this Society in 1903, and published in greater detail in 1905, regarding the origin of major groups, or phyla, of the animal kingdom.

The older evolutionists, for example, undertook to show by what transformations of the developed body an annelid or arthropod could be converted into a vertebrate. It was supposed that the invertebrate turned upside down, its mouth closed up and a new mouth formed, and many other changes occurred which would be absolutely impossible in any developed animal. Similar impossible translocations of organs of adults had been proposed to explain the origin of inverse asymmetry, as for example in those rare cases in man where the heart is found on the right side instead of the left and all other asymmetrical organs are reversed in position. When it was discovered that such inversions of all the organs of sinistral as compared with dextral snails could be traced back through the embryology to the early egg cell, it was evident that this inversion was due to relatively slight changes in the locations of cytoplasmic substances in the egg cell; such changes are now known to be caused, in the last analysis, by genes. Similarly, when it was discovered that the location of the principal organs of several different phyla could be traced back to the pattern of localization of special substances in their eggs, I suggested that relatively slight changes in the localization of these substances would bring about the characteristic differences in the location of the organ systems of vertebrates as compared with invertebrates. Thus, instead of turning a developed worm or arthropod upside down, and making many impossible translocations of its organs, it would be relatively simple to convert one type into another by translocations of cytoplasm within a single cell, such changes ultimately being caused by gene activity. Unfortunately, this suggestion, like that of Goldschmidt just mentioned, is at present without experimental proof.

V

Adaptations have always been the chief marvel of the living world and their method of origin is still the greatest problem of biology. The only natural explanation that has as yet been established is Darwin's principle of the elimination of the unfit and the survival of the fit. There is abundant evidence, both observational and experimental, that this principle is true, but when we load upon it the obligation of explaining all the marvelous adaptations and combinations of adaptations that every living thing possesses, the doubt arises as to whether this principle alone can support the enormous burden. I have long felt, along with Cope, Osborn, and many others, that some additional factor is needed to explain such universal adaptations. And Darwin himself felt the force of this, for he said that he never thought of attempting to explain the origin of such a complex and wonderfully coordinated structure as

the eye without a shudder. He sought refuge, as did Cope and many others, in the inherited effects of use and disuse as an aid to natural selection, but this refuge is now denied us, for the evidences from genetics are conclusive that such effects are not inherited.

A solution that has found favor with many geneticists lies in the vastly greater duration of past time than was formerly allowed for organic evolution. Darwin estimated that past evolution must have required something like 400 million years. Lord Kelvin speaking for the physicists of his day would allow him not more than 100 million years. But the physicists, astronomers, and geologists now say that the earth was ready for life at least 1,000 million years ago, and geneticists console themselves with the thought that given almost infinite time and almost an infinitude of mutations, almost anything could happen. But after all they cannot help feeling that this is not a satisfactory solution of the vast problem of fitness—at present by far the greatest problem of biology.

Another possible solution of this problem was first pointed out by Roux in his hypothesis of "the struggle of the parts" and by Weismann in his doctrine of "intrapersonal selection." In short, selection acts not only on developed organisms and the correlations of all their parts and organs, but much more on embryos, germ cells, and combinations of chromosomes, genes, and mutations; indeed, it acts to preserve a proper balance between all structures and processes of the organism. Thus unfavorable combinations may be eliminated at their beginnings, and the more unfavorable they are the earlier they are eliminated.

I have proposed (1921) a still further application of the selection principle to all the reactions of living things. We know that all organisms are differentially sensitive; that is, they move or grow toward certain sources of stimuli and away from others, and in general they respond positively to stimuli which we would call pleasant or satisfactory, and negatively to those which we call unpleasant or unsatisfactory. In short, they are generally able to differentiate and select between that which is satisfactory and that which is not. No one can at present explain this property of life, but apparently it is a general characteristic of all living things. It characterizes the behavior of germ cells and embryos as well as adult organisms. It is the basis of that form of behavior known as "trial and error"; it is fundamental to all learning and is the beginning of intelligence and wisdom in man as well as in higher animals. This capacity to differentiate and select is not unlike the "archaesthesia" of Cope, and it is at bottom an extension of the selection principle to the reactions of organisms—but with this difference, that whereas in Darwinian selection the selector or eliminator was

found exclusively in the environment, in this conception the organism itself also selects or eliminates. There is no mechanistic explanation of this property of life, but the same is true of many other properties of living things. Because we cannot at present explain mechanistically the properties of the organization of protoplasm and its capacities of assimilation, reproduction, and sensitivity is no ground for denying that these properties exist, and the same is true of the property of organic adaptation. But given these properties, science can explain in a mechanistic, that is, in a causal manner, multitudes of structures and functions and reactions that have arisen in the course of evolution.

It seems to me that recent theories of evolution have too often left out of account these fundamental properties of life. Assigning all evolution to externally caused mutations and to environmental selection neglects the fact that the organism is itself a living, acting, and reacting system. Life is not merely passive clay in the hands of environment, but is active in response to stimuli; it is not merely selected by the environment but is also itself ever selecting in its restless seeking for satisfaction. Macfarlane (1918) has called this property of organisms "proenvironment" and has assigned to it an important function in evolution. Cuenot (1911) has shown that many animals seek and find by a process of trial and error those environments for which they are by nature best adapted, and he calls this "preadaptation." By a similar process, namely the elimination of unsatisfactory responses, most of the individually acquired adaptations of organisms may be explained. Such acquired adaptations as the repair of injuries, the regeneration of lost parts, acclimatization to high altitudes or temperatures, neutralization of poisons, and immunity to disease, which were at one time hailed as a "deathblow to Darwinism", may be explained by an extension of the Darwinian principle of the elimination of the unfit to the multitudinous reactions of organisms.

From my earliest introduction to the science of biology I have been an admirer of August Weismann. Of late it has become fashionable to decry the speculations and theories of Weismann, since they were not based on experiment. But no one can truthfully deny that his logical deductions were a powerful stimulus to research and that many of them have been confirmed in a truly remarkable manner by recent work. He maintained, long before it was demonstrated by genetics and cytology, that the hereditary substance consists of discrete particles, his determinants, arranged in a linear series in the chromosomes. His prediction that one of the maturation divisions in the formation of the egg and sperm must lead to the reduction of the chromosomes in those cells to one-half the

number present in somatic cells was almost as brilliant an example of scientific prophecy as was the prediction of the existence and position of the planet Neptune. And, finally, his explanation of the origin of fitness in the living world is still, I think, the best scientific conception that has ever yet been offered. I cannot better express my own views on this subject than by closing with these words from the preface of his last book (1902) :

Although I may have erred in many single questions which the future will have to determine, in the foundation of my ideas I have certainly not erred. The selection principle controls in fact all categories of life units. It does not create the primary variations but it does determine the paths of development which these follow from beginning to end, and therewith all differentiations, all advances of organization, and finally the general course of development of organisms on our earth, for everything in the living world rests on adaptations.

LITERATURE CITED

In general only the earliest in a series of papers, or a later one which presents a general summary, is cited.

BAILEY, L. H.

1896. The survival of the unlike. *Proc. Amer. Philos. Soc.*, vol. 35.

BATESON, W.

1894. Materials for the study of variation: Discontinuity in the origin of species. London.

BLAKESLEE, A. F.

1921. Types of mutations and their possible significance in evolution. *Amer. Nat.*, vol. 55, pp. 254-267.

BLAKESLEE, A. F., and AVERY, B. T., JR.

1919. Mutations in the jimson weed. *Journ. Heredity*, vol. 10, pp. 111-120.

CLAUSEN, R. E.

1928. Interspecific hybridization in *Nicotiana*, VII. *Univ. Calif. Pubs. in Bot.*, vol. 11, pp. 177-211.

CLAUSEN, R. E. and GOODSPEED, T. H.

1925. Interspecific hybridization in *Nicotiana*, II. *Genetics*, vol. 10, pp. 278-284.

CONKLIN, E. G.

1896. The factors of organic evolution from the embryological standpoint. *Proc. Amer. Philos. Soc.*, vol. 35, pp. 78-88.

1921. Problems of organic adaptation. *Rice Inst. Pamphlet*, vol. 8, pp. 299-380.

COPE, E. D.

1896. The primary factors of organic evolution. Chicago.

CUENOT, L. C.

1911. *La genèse des espèces animales*. Paris.

DE VRIES, H.

1901, 1903. *Die Mutationstheorie*. Leipzig.

FISHER, R. A.

1930. *The genetical theory of natural selection*. Oxford.

GALTON, F.

1892. *Hereditary genius*, 2d ed. London.

GOLDSCHMIDT, R.

1929. Experimentelle Mutation und das Problem der sogenannten Parallelinduction Versuche an *Drosophila*. Biol. Zentralblatt, vol. 49, pp. 437-448.

HALDANE, J. B. S.

1932. The causes of evolution. London.

HURST, C. C.

1932. The mechanism of creative evolution. Cambridge Univ. Press.

JOHANNSEN, W.

1903. Ueber Erbllichkeit in Populationen und in reinen Linien. Jena.

JOLLOS, V.

1930. Studien zum Evolutionsproblem. Biol. Zentralblatt, vol. 50, pp. 541-554.

1931. Gerichtete Mutationen und ihre Bedeutung für das Evolutionsproblem. Idem, vol. 51, pp. 137-140.

KARPECHENKO, G. D.

1929. Konstantwerden von Art- und Gattungsbastarden durch Verdoppelung der Chromosomenkomplexe. Der Züchter, vol. 1, p. 133.

1929. A contribution to the synthesis of constant hybrids of three species. Proc. All-Russian Cong. Genet., Plant and Animal Breeding, vol. 2, p. 277.

LEVITSKY, G. A., and BENETZKAIA, G. K.

1929. Cytological investigations of constant intermediate rye-wheat hybrids. Idem.

LINDSTROM, E. W.

1932. A fertile tetraploid tomato cross—sterile with diploid species. Journ. Heredity, vol. 23, pp. 115-121.

MACFARLANE, J. M.

1918. The causes and course of organic evolution. New York.

MCCLUNG, C. E.

1902. The accessory chromosome. Sex determinant? Biol. Bull., vol. 3, pp. 43-84.

MONTGOMERY, T. H. JR.

1901. A study of the chromosomes of the germ cells of Metazoa. Trans. Amer. Philos. Soc., vol. 20.

MORGAN, T. H.

1933. The scientific basis of organic evolution. New York.

MULLER, H. J.

1927. Artificial transmutation of the gene. Science, vol. 66, pp. 84-87.

1929. The method of evolution. Sci. Monthly, vol. 29, pp. 481-505.

NEWTON, W. C. F., and PELLEW, C.

1929. *Primula kewensis* and its derivatives. Journ. Genetics, vol. 20, pp. 405-467.

OSBORN, H. F.

1932. Aristogenesis, the creative principle in the origin of species. Amer. Nat., vol. 68, pp. 193-235.

PAINTER, T. S.

1934. Salivary chromosomes and the attack on the gene. Journ. Heredity, vol. 25, pp. 465-476.

PLOUGH, H. H., and IVES, P. T.

1934. Heat induced mutations in *Drosophila*. Proc. Nat. Acad. Sci., vol. 20, pp. 268-273.

STEVENS, N. M.

1905. Studies in spermatogenesis. Carnegie Inst. Washington Publ. No. 39, pp. 3-32.

SUTTON, W. S.

1902. On the morphology of the chromosome group in *Brachystola magna*. Biol. Bull., vol. 4, pp. 24-39.

WEISMANN, A.

1902. Vorträge über Descendenztheorie. Jena.

WILSON, E. B.

1905. Studies on chromosomes. I. The behavior of the idiochromosomes in Hemiptera. Journ. Exp. Zool., vol. 2, pp. 371-405.

HOW THE FISHES LEARNED TO SWIM¹

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Through investigations during the last few years, an astonishing amount of new information has been discovered concerning the earliest known vertebrates. Not only have a number of new orders, families, genera, and a profusion of new species been described, but what is more important, investigators have succeeded in classifying all the new and old discoveries into a fairly reliable system and to outline the general relationships between all these various forms.

In my first figure I have attempted to show the latest systematic classification of both fishes and fishlike forms based chiefly upon the investigations of Kiaer, Stensiö, Broili, Gross, and others. We see the first class formed by the ostracoderms, which are most nearly related to the recent cyclostomes or lampreys. They reach their greatest abundance in the upper Silurian and through the entire Devonian but become extinct with the latter period. Characteristic of almost all Paleozoic forms is the presence of a more or less strongly developed dermal armature of mail which covered the head and frequently also the anterior part of the body.

The true fishes, which form a second class of craniate vertebrates, are subdivided into three large divisions: the Placoderms, the Elasmobranchs or sharklike forms, and the Teleostomes or bony fishes. Of greatest interest to us are the Placoderms, which are the best-known group of the oldest true fishes. They began to appear in the upper Silurian, but are chiefly characteristic of the Devonian period. At the transition to the Carboniferous the Placoderms disappeared. They, also, had a strong dermal armature covering both the head and the anterior part of the body.

The earliest remains of the forms belonging to the two last divisions, the Elasmobranchs and Teleostomes, are also known from the Devonian. But only a few groups of these divisions reached any abundance as early as the Paleozoic era.

¹ Translation published by permission from *Naturen*, vol. 58, nos. 7 and 8, Bergen, July and August 1934.

From the time of the classic investigations by Kovalevski and especially by Dollo, there have been attempts in paleontology to introduce a more biological method of investigation. That is to say, workers have not been content with giving merely a description of

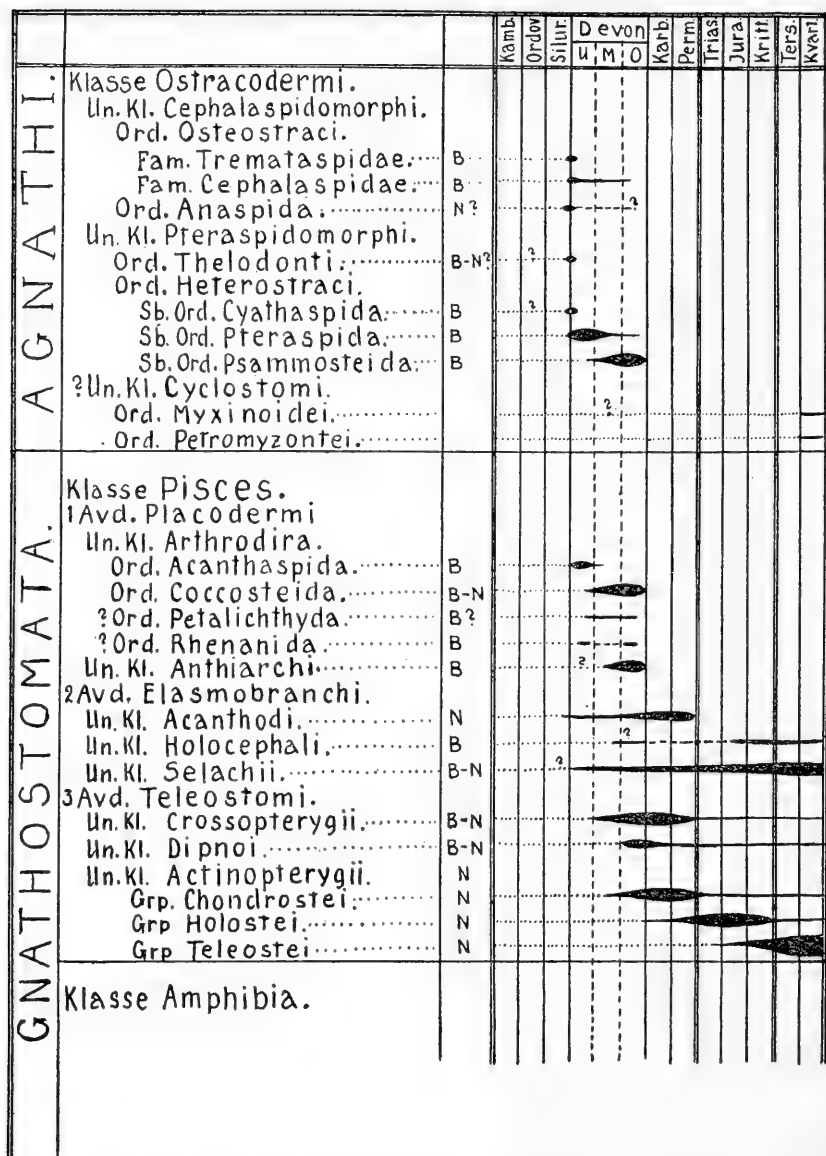


FIGURE 1.—Systematic subdivisions of fishlike forms and fishes based upon the recent investigations. Agnaths, the forms without jaws, comprising only one class—the Ostracoderms. Gnathostoms, or forms with true jaws, comprising in addition to the fishes all other vertebrates (amphibians, reptiles, birds, and mammals). According to Stensl6's investigations the Placoderms must be regarded as belonging to the Elasmobranchs. (Modified after Gross.)

the fossil remains, but have also endeavored to analyze them and reconstruct them not only in regard to their skeleton but also in regard to their apparent adaptations and manner of life, in a word, their biology. The efforts have then been particularly directed toward the elucidation of the relationship between form and function in the various fossil animals, and to solve this problem wide use has been made of comparisons between fossil and recent forms. During later years Osborn in America and Abel in Germany, among others, have worked very intensively in this direction. Abel has even introduced a new name for this branch of paleontology which he has designated as paleobiology, i. e., the investigation of the manner of life of the extinct animals.

In this article I will attempt to deal with some aspects of the biology of the oldest known vertebrates, the fishes and fishlike forms. Through analysis of their structures it is possible to show the gradual change in their adaptations and to draw various general conclusions from this. Investigations of the biology of different groups of Paleozoic fishes have been undertaken by many others (e. g., Kiaer, Jaekel, Abel), but so far as I know there has been no previous attempt to give a comprehensive picture of the gradual development of the different adaptations of these peculiar forms. I shall therefore attempt to say a few words about the biology of the oldest known fishes and fishlike forms, that is, the biology of the Placoderms and Ostracoderms. They have all lived in the water, and it is therefore of great interest to attempt to elucidate their adaptations to life and to movement in the water, that is to swimming.

But before we proceed to a discussion of these forms in greater detail, it will be better to review briefly the adaptations to swimming which we find among other vertebrates.²

It is possible to distinguish three separate groups of organs in all swimming animals: (1) the organs which cause the forward motion itself, that is the organs of locomotion proper, or propulsion, (2) the organs of balance serving to maintain the equilibrium of the animal, and finally, (3) the steering organ by which the direction of the motion is determined, up or down, right or left. These different groups of organs may be very differently developed in different kinds of animals, but all the various modifications, in which adaptations to movement through water are found, may nevertheless be classified into four main groups or types.

The first type, which also represents the most perfect one, is best shown by the free-swimming fishes (fig. 2, A, B, C). We might for

² More detailed descriptions of the different forms of adaptation among swimming vertebrates can be found in Abel's "Palaeobiologie", 1912.

instance consider the mackerel as an example of this type. The body is compressed (B), torpedo-shaped (A), and entirely smooth. The most important organ of locomotion is the caudal fin. Powerful strokes of the tail caused by a wavelike motion of the entire body (C), drives the fish forward with great speed. As organs of equilibrium we find the dorsal and anal fins and frequently also the ventrals. The pectoral fins and partly also the ventrals per-

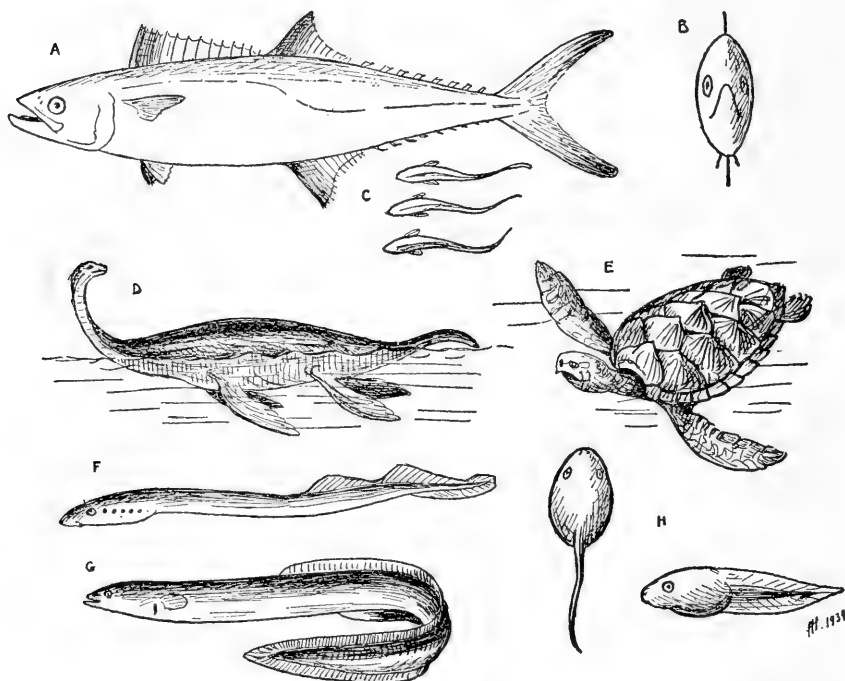


FIGURE 2.—Four different types of adaptations to movement in water. *First type*, the most perfect type. Torpedo-shaped body with caudal fin as propulsive organ; A and B, mackerel seen from the side and from the front; C, movements of the fish while swimming. *Second type*: Plump, broad body, extremities as organs of locomotion; D, *Plesiosaurus*, from the upper Cretaceous; E, recent sea turtle. *Third type*: Snakelike form, the entire body serves as organ of locomotion; F, lamprey; G, eel. *Fourth type*: The tadpole type, the least efficient form; H, tadpole from above and from the side.

form the function of steering. Thanks to all these highly developed adaptations the nectonic, that is the free-swimming, fishes, are the most perfect swimmers we know, moving in all directions with an astounding elegance and ease. Almost the same type of adaptations are also found among the recent whales and the extinct Ichthyosaurs.

The second type, which can best be compared with a rowboat, is practically unknown among fishes, but is frequently seen in marine reptiles (fig. 2, D, E) and diving birds. It is less perfect. In this

case the anterior, the anterior and posterior, or more rarely the posterior extremities alone serve in the capacity of oars. They force the short and plump body through the water by powerful strokes, which may perhaps best be compared with the wing strokes of a bird. These forms are as a rule without special organs of equilibrium or for steering purposes, as the extremities alone serve in all three capacities, that is both for propulsion, balancing, and steering of the body. In some cases, however, the posterior extremities or the tail may serve as a lateral rudder. As the best examples of this type one might mention the sea-turtles (E), the extinct large presiosaurs, and the penguins.

The third type must be regarded as even less adapted to swimming. It is the snakelike type (fig. 2, F, G). The animal swims by means of a wavelike motion of the entire body. As balancing organs there are as a rule more or less well-developed median fins. Special organs for steering are usually absent, as the very flexible body takes care of the steering without any special fins. As examples of this type, one can mention the recent cyclostomes or lampreys (F), eels, and a number of other fishes. Many of the recent or extinct amphibians and reptiles also approach this type more or less closely.

The fourth group is of a more distinct type. It has, so far as I know, not previously been separately defined. In its purest form it is not found either among adult fishes, amphibians, or reptiles, but we encounter it among the larvae of tunicates and amphibians. It is best represented by the tadpole (fig. 2, H). The large, somewhat flattened, round "cephalothorax" (head and anterior part of the body) is without any indication of fins or any other appendages or organs of equilibrium. The tail is strongly compressed, fairly long, with a slightly thickened central core and wide, finlike rims above and below. The tail of the tadpole combines in itself all the three functions of locomotion: Propulsion, balancing, and steering. The heavy and clumsy "cephalothorax" participates only quite passively in the swimming. Perhaps it may have some function as a gliding plane. Anybody who has seen a tadpole will know that it cannot be considered among the good swimmers. Their adaptations to swimming are very imperfect, and we also see that they spend the greatest part of their time resting upon the bottom. But as soon as the posterior extremities develop and start to grow, the tadpole begins using them as organs of equilibrium and steering, and the swimming then immediately becomes much more efficient.

The tadpole shape with a large head and anterior part of the body (cephalothorax) and a thin, flat tail is not very rare among bottom fishes, but they then always have paired and unpaired fins to help

them keep their balance and to steer the body; these fishes are therefore better adapted to swimming than are the young tadpoles.

After thus having described the four most important types of adaptations to swimming, we will now consider the modifications of the various old Paleozoic fishes and fishlike forms and try to determine to which of these four types their various representatives have belonged.

We will start with the first class, that of the Ostracoderms, which is divided into two subclasses—Cephalaspidomorphi and Pteraspidomorphi (fig. 1).

The Cephalaspidomorphi are known from the Upper Silurian and throughout the Devonian. And we can here differentiate two sharply defined orders; the Osteostraci and the Anaspida.

The Osteostraci, which are particularly well known thanks to the recent investigations by Stensiö, begin to appear in the Upper Silurian, in which they are represented by some curious flat forms shown in the upper left of our figure 3. This picture shows the so-called *Tremataspis* from the Upper Silurian of Estonia.

The head and anterior parts of the body are covered by a continuous shell. On the dorsal side we find two close-set eyes (fig. 3) with a pineal organ between them and a single nostril in front. At the sides of the shell there are some peculiar sense organs, which Stensiö interprets as electric organs. On the ventral side (fig. 3) there is a large opening anteriorly, the so-called mouth-gill opening or oralo-branchial aperture, which is covered only by smaller plates. In this area we find the mouth anteriorly and the gill-openings posteriorly on the sides. The tail is small and thin, covered with large scales, and distinctly triangular in cross-section (fig. 3). The flat belly forms the underside of the triangle. Where the sides join there is a peculiar comblike row of scales forming three longitudinal fringes. These rows of scales are probably the first indications of the medio-dorsal and lateral fin folds. The caudal fin itself is comparatively small, heterocercal, that is with the upper lobe larger than the lower, and is covered with scales. How then has this creature been able to move through the water?

A glance at the reconstruction of this form is sufficient to show a striking similarity in the shape of *Tremataspis* and that of a tadpole. Both have a plump, rounded cephalothorax and a thin rather flat tail. Both are without paired fins and have no well-developed organs of equilibrium. We can consequently say with certainty that *Tremataspis* was a bottom form, swimming only poorly and uncertainly. Its organs of propulsion, balance, and steering are, as in the case of the tadpole, all represented only by the tail and the posterior part of the trunk. But it is nevertheless

more specialized than in the tadpole. In *Tremataspis* there are three conspicuous longitudinal folds which help to maintain equilibrium and a striking heterocercal tail increasing the effectiveness of the forward propulsion.

Ord. Osteostraci.

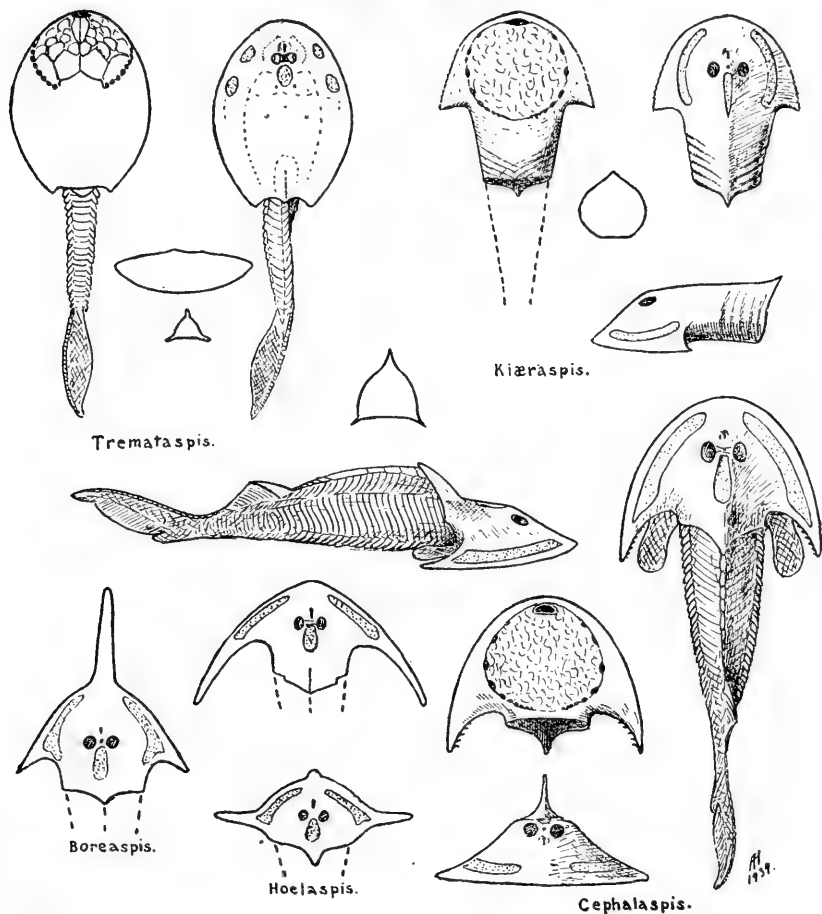


FIGURE 3.—Different representatives of the order Osteostraci (after Patten and Stensiö). *Tremataspis* from Estonia; from below, above, and cross-section of the body and of the tail. *Kiaeraspis* from Spitzbergen; cephalothorax from below, above, from the side, and posterior part in cross-section. *Cephalaspis* from England; from above, from the side, head from below, and in frontal view. *Boreaspis* from Spitzbergen. *Hoelaspis* from Spitzbergen. Long-spined *Cephalaspis* from Spitzbergen.

If we consider the later osteostracs such as *Kiaeraspis* (fig. 3), we will see that evolution has progressed further. In this form, the cephalothorax is more specialized and divided into a section of the head and a section of the body. On the boundary between these two sections some distinct flat spines have been developed. The

structure of the tail was probably similar to that in *Tremataspis* but broader. In this form we, therefore, have an addition to the three longitudinal folds on the posterior part of the body in the form of the two flat projections on the sides of the cephalothorax, which serve as organs of equilibrium and at the same time increase the surface of the cephalothorax and thus function also as an accessory gliding surface.

The most highly specialized forms of the Osteostraci are the Cephalaspids (fig. 3) which are still better adapted to swimming. In these forms, practically only the head is covered by a hard shell, while the entire rest of the body has scales only and is therefore movable. The tail is large and the median and lateral folds are more strongly developed. In addition, most of these forms have a distinctly developed dorsal fin.

The projections on the side of the head already indicated in the earlier forms have become larger—some even very large. On the posterior part of the head a third median dorsal projection is distinctly developed and may reach a large size in some species. We finally see in the bights between the lateral projections two peculiar lobe-shaped organs of the nature of paired, movable pectoral fins.

All this seemed to indicate that the Cephalaspids were considerably better swimmers than *Tremataspis*, and they are no longer so tadpolelike but approach the true fish type more closely. The tail is still the most important organ of propulsion, and the lateral and median folds, the dorsal fin on the body, and the lateral and median projections on the head are excellent organs of equilibrium. We finally have the paired pectoral fins as effective organs of swimming. Even if *Cephalaspis* was a typical bottom form, it could certainly swim as well as, for instance, one of our recent sculpins.

We also see very clearly how the different Osteostraci became gradually better and better adapted to swimming. Parallel with this development a gradual reduction in the thickness of the external skeleton also took place. In the oldest form such as *Tremataspis* the shell is thicker, in the younger forms it is more and more strongly reduced as particularly pointed out by Stensiö. With this reduction the fish becomes lighter and in consequence better fitted for swimming. The second group of the Cephalaspidomorphi (fig. 1) are the so-called Anaspids, which first became really known after the thorough investigation of recent finds published by Kiaer. The Anaspids (fig. 4) are only known with certainty from the upper Silurian, but some uncertain remains have also been described from the Upper Devonian. They have a strongly compressed torpedo-shaped body with a pointed snout and a powerful so-called hypocer-

cal tail, that is, the lower lobe of the tail is more strongly developed than the upper. The head and trunk are covered with fine, thin scales. Everything therefore indicates that we have a relatively good swimmer, a highly specialized form. The adaptations of the Anaspids to swimming are nevertheless not as perfect as in the recent free-swimming species. The organs of equilibrium in the Anaspids consist of only a row of spinelike fulcrum scales along the back and a relatively strong anal fin. There are, in addition, on both sides of the body immediately behind the gill-opening two peculiar immovable spines. They must certainly have corresponded to the paired fins in other fishes, but it is doubtful whether they could have any significant function as organs of steering or equilibrium as they were much too thin and narrow. The lack of organs

Ord. Anaspida.

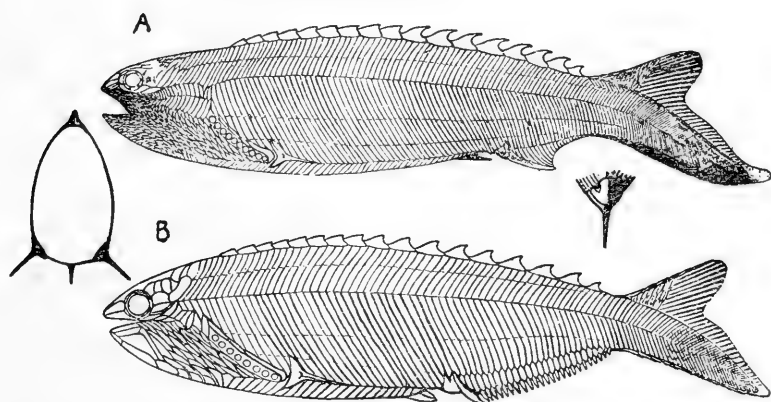


FIGURE 4.—Two representatives of the order Anaspida: A, *Pterolepis*; B, *Remigolepis*. Cross-section of the body and the anal fin in anterior view (after Kiaer).

of equilibrium is a very peculiar phenomenon. We know that all torpedo-shaped free-swimming fishes are in a state of unstable equilibrium in water, as the lower part of the body (with the abdominal cavity) is lighter than the solid muscular back. We see this most distinctly in sick or dead fishes which always swim or float with the side or the belly up. In a living condition they maintain their upright position in the water by motions of the tail, the unpaired and chiefly the paired fins. It must have been difficult for the Anaspids to maintain their equilibrium without considerably developed fins. Perhaps the peculiar hypocercal tail with the downward-directed thick body axis helped them in keeping the right position in the water. In spite of all this, however, we must still consider the Anaspids as having been comparatively good swimmers, even if their adaptations to swimming were not as perfect as we find them in the youngest true fishes.

The second large subclass of the Ostracoderms (fig. 1), the Pteraspidomorphi, have a more peculiar build. Some of the oldest forms, which are known from as far back as the Ordovician, are the so-called Thelodonti (fig. 5). The entire body including head, tail, and fins, is evenly covered with small, close-set scales. The head and the foremost part of the body, the "cephalothorax", is broad and flat; the hindmost part, on the other hand, is narrow and the tail probably

Ord. Thelodonti

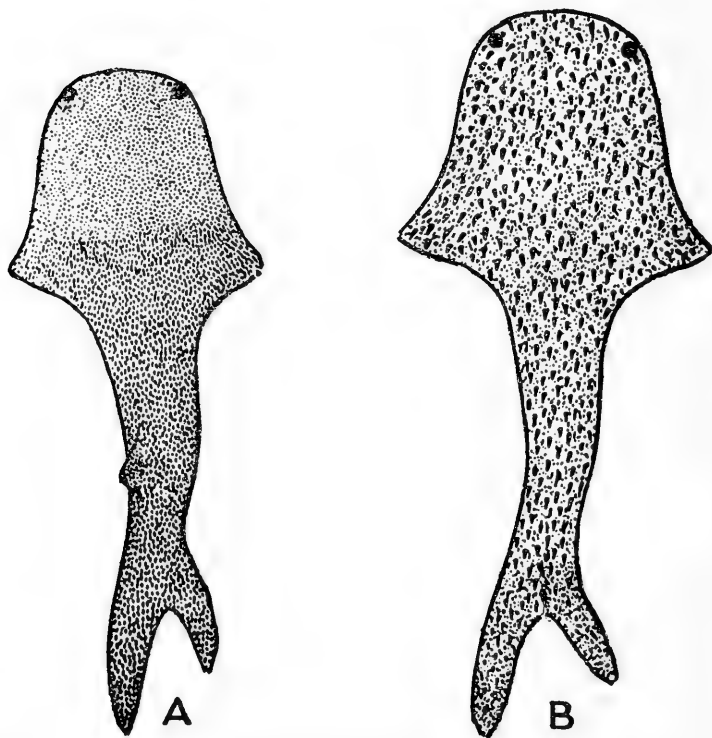


FIGURE 5.—Two representatives of the order Thelodonti (after Traquair). A, *Lanarkia* from Scotland; B, *Thelodus* from Scotland.

hypocercal. The postero-lateral corners of the cephalothorax are produced into a pair of flat, brimlike fins. On the posterior part we find a small anal and dorsal fin. In their shape the Thelodonti remind one very closely of the oldest Osteostraci which we have just described, and also of the tadpole. We have certainly to deal with bottom forms, which were swimming around like tadpoles even though they had organs of equilibrium in the form of lateral flaps and also a median fin.

More interesting is the development of the second group of the Pteraspidomorphi, the so-called Heterostraci, which are known from the upper Silurian to the Devonian (fig. 1).

Sub.Ord. Cyathaspida.

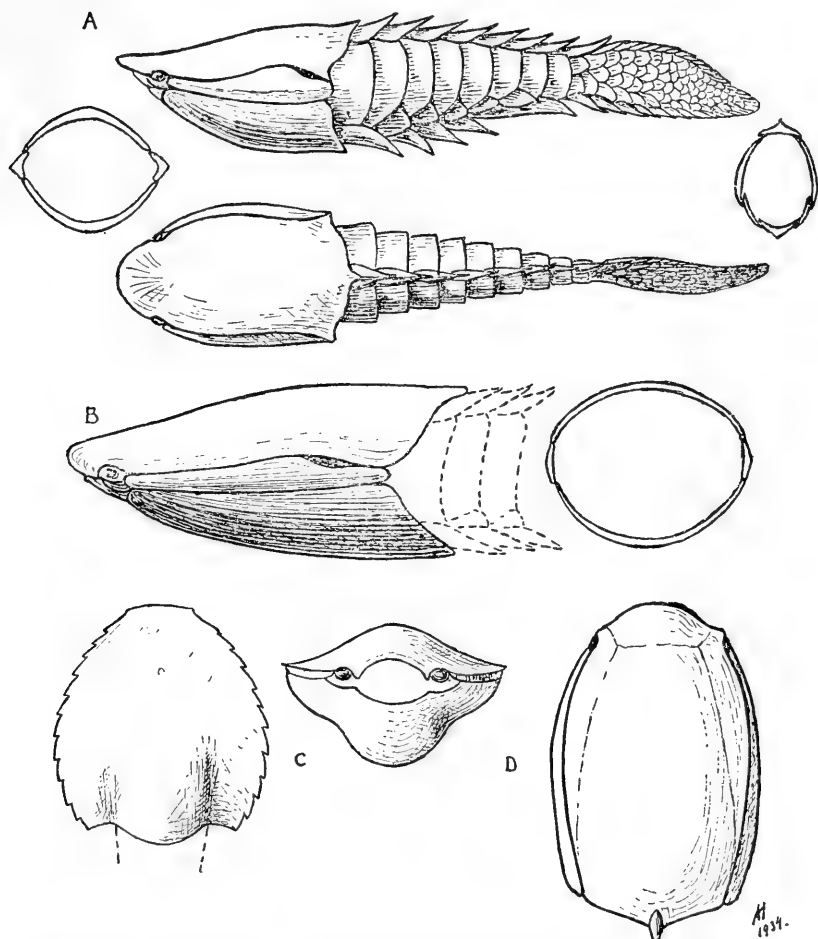


FIGURE 6.—Different representatives of the suborder Cyathaspida (after Kiaer). A, *Anglaspis* from Spitzbergen; from the side, from above, and cross-section of anterior part of body and of the tail. B, *Poraspis* from Spitzbergen; from the side, and cross-section of the shields. C, *Utenaspis* from Spitzbergen; head shields from above, and in frontal view. D, *Cyathaspis*, cephalothorax from above.

The oldest (Cyathaspids), which have been thoroughly described by Kiaer, resemble in their shape the oldest Osteostraci (fig. 6). The head and the foremost part of the body are also covered by a shell, which, however, does not consist of a continuous armature, as in *Tremataspis*, but of two large plates, one dorsal and one ventral.

The form of the posterior part of the trunk and the tail are not as well known, as these parts have been found completely preserved only in one single species from Spitsbergen. The posterior part of the trunk and the tail were probably considerably shorter and thicker than in *Tremataspis*, and covered by very solid, thick scales. The structure of the cephalothoracic armature varies considerably in the different forms. In some it is more oval and rather flat (fig. 6, A, B), in others more elongate and almost cylindrical with a circular cross-section.

How were these forms able to move through the water? They certainly had no paired fins nor any unpaired ones and they also lacked any distinct spines. The only movable part of the animal, the posterior trunk and tail, were covered by exceptionally solid and thick scales, which prevented the possibility of any strong and lively movement. Thus we see that the primitive Cyathaspids had neither any organ of equilibrium nor steering organs and that furthermore their organ of propulsion, the hind part of the body and the tail, were also less flexible and movable than in tadpoles or the oldest Osteostraci. From this we can conclude that the Cyathaspids were very poor swimmers and spent their time chiefly on the bottom, perhaps partly buried in sand and mud.

The next step in the adaption of the Heterostraci is found in the large group of the true Pteraspids (fig. 7). They are all flatter, more conspicuously compressed dorso-ventrally. The dorsal shield, which was undivided in the Cyathaspids, has been split into several separate plates. Of greater interest, however, is the development of the different spines and projections.

To begin with, we find distinct lateral projections on each side behind the gill-opening (fig. 7, A 3). These projections vary greatly in different forms, as one may see from the figure. In some it assumed almost fantastic dimensions (fig. 7, D, E), in others it was almost completely obliterated (fig. 7, C). As in the case of the similar projections in Cephalaspids it is evident that these spinelike parts in the Pteraspids served primarily as organs of equilibrium, but secondarily also, and then particularly in the forms with very large spines, as a gliding organ. Apart from these two symmetrical lateral spines we find also a median dorsal spine developed in most of the Pteraspids. This dorsal spine is located at the posterior end of the dorsal shield and is directed obliquely upward and backward (fig. 7, A, B, C, D). This spine corresponds entirely to the comblike development of the posterior part of the cephalic shield in the Cephalaspids and must assuredly have served as an organ of equilibrium.

Sub Ord. Pteraspida & Sub Ord Psammosteida.

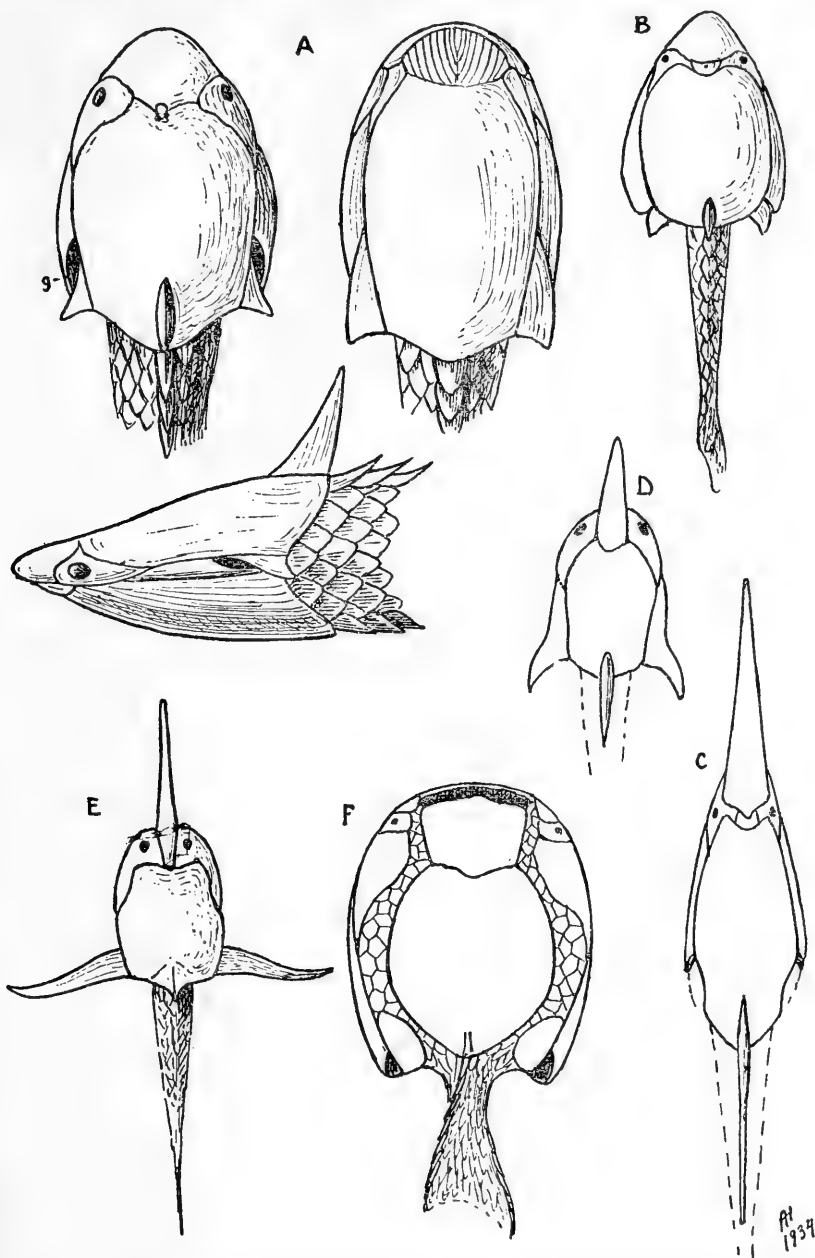


FIGURE 7.—Different representatives of the suborders Pteraspida and Psammosteida (after Kiaer, Bryant, Gross, Lerich, and Traquair). A, a small *Pteraspis* from Spitzbergen; from above, below, and from the side. B, *Protaspis*, a form from America; seen from above. C, *Pteraspis* from Germany. D, *Pteraspis* from France. E, *Dyraspis*, a new form from Spitzbergen. F, *Drepanaspis* from Germany.

Paired fins have not been found in the Pteraspids. The tail and the posterior part of the trunk was, on the other hand, more flexible and much more slender than in the Cyathaspids (fig. 6, A). The large, thick Cyathaspid scales have been split into numerous small rhombic scales, which also cover the large hypocercal caudal fin (fig. 7, A, B, E). The cross-section of the tail is a more or less rounded oval, not triangular as in the Cephalaspids (fig. 3) and is without any indications of lateral folds.

Generally speaking, the Pteraspids must therefore have been bottom forms, which by means of powerful tail strokes lifted themselves from the bottom to glide through the water on their large, wide, lateral spines in the manner of a modern gliding plane.

Parallel with this development, again corresponding entirely to conditions among the Cephalaspids, we find also that a strong reduction in the thickness of the shields has taken place. In the youngest Pteraspids (from the Lower Devonian) the dermal armature was paper-thin and very light. We thus see that the Cyathaspid-Pteraspid line of evolution in its adaptations to swimming has not reached as far as the Tremataspid-Cephalaspid line which we first described. The latter gradually acquired both organs of equilibrium in the form of spines and lateral and median skin folds, and steering organs in the form of movable paired fins. The Pteraspids did not get further than to the development of lateral gliding spines. No indication of paired fins or lateral fin folds is known in this group.

Another line consisting of the Heterostraci, the Drepanaspids and Psammosteids (fig. 7, F) has followed another path of evolution and remain typical flat bottom forms with short tail, weakly developed lateral spines and no dorso-median projections. We know forms of this general character from the Lower to the Upper Devonian. Some of them reach a considerable size, over 1 meter in length.

The recent Cyclostomes, comprising the lampreys and hagfishes, are, as already previously mentioned, closely related to the fossil Ostracoderms. They also have not advanced very far in their adaptation to swimming. They are entirely snakelike (fig. 2, F), winding their way through the water. A median fin fold runs along the posterior part of the back around the tip of the tail and a distance forward along the ventral side. Neither do we find in the Cyclostomes any trace of paired fins. They have special organs of locomotion or of steering, and their organs of equilibrium are only represented by the median fin fold.

We thus see that the primitive fishlike forms of the order Agnathii (fig. 1) have not attained any specially high adaptation to swimming. Only one single family, the Cephalaspids, had distinctly differentiated organs of steering, equilibrium, and propulsion, while the body,

on the other hand, was not torpedo-shaped but entirely flat, of a typically benthonic character. A second group, the Anaspids, had torpedo-shaped bodies, but were, on the other hand, without any highly developed organs of steering and equilibrium.

When we now turn our attention to the class Pisces, or the true fishes (fig. 1), then it is particularly the so-called Placoderms which are of interest. With the Elasmobranchs,³ they belong to the oldest-known true fishes, and their first remains are found at the transition from the Silurian to the Devonian. These oldest forms belong to

Un. Kl. Arthrodira.

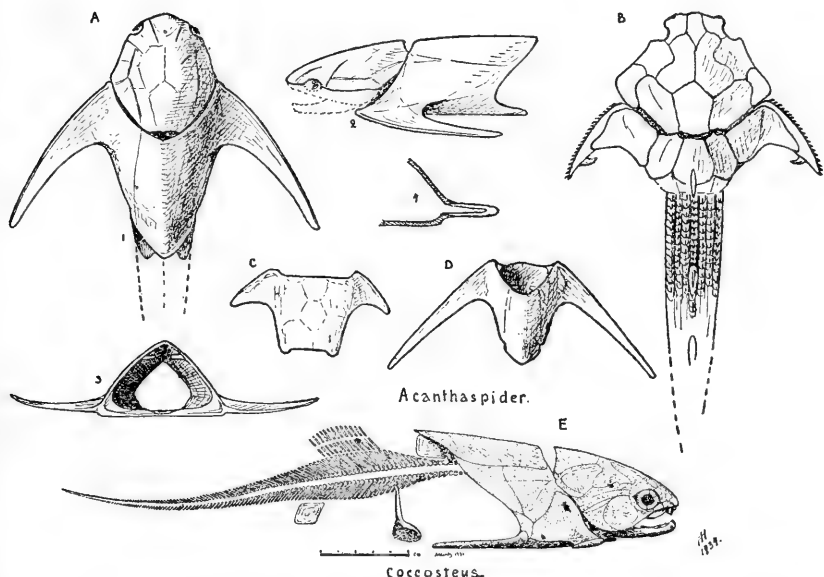


FIGURE 8.—Different Arthrodira (after Broili and Heintz). A, *Acanthaspis* from Spitzbergen; (1) from above, (2) from the side, (3) body shield seen from the front, (4) cross-section of a lateral spine and the side of the body shield. B, *Acanthaspis* from Germany; with completely preserved posterior part of trunk. C and D, two different types of body shields of *Acanthaspids* from Spitzbergen. E, *Coccoosteus*, an Arthrodire from the Middle Devonian; internal skeleton strongly calcified.

the subclass Arthrodira and the order Acanthaspida, which has become particularly well known through the discoveries in the Lower Devonian of Spitzbergen. Everything seems to indicate that this order must be regarded as the central systematic unit among the Arthrodires, from which the different other families have sprung.

The head and the foremost part of the body of the Acanthaspids (fig. 8, A, B) were covered by a solid shield as in all other Arthrodira. But whereas we find the shield of the head and body in the Ostracoderms united into a single shell, the cephalothorax, the shields of the

³According to Stensiö's investigations, the Placoderms must be regarded as belonging to the Elasmobranchs.

Arthrodira are divided into two separate parts: the head shield and the body shield, which are movable and connected with each other by a double joint, which permits a more or less free movement up or down of the head in relation to the body. The head in *Acanthaspis* is flat, the small eyes are situated laterally far forward in the skull. Immediately in advance of them are the nostrils.

The body shield in the *Acanthaspids* is rather low (fig. 8, A 2, 3; fig. 9, A), entirely flat below and somewhat arched above, with a sharp bend along the median line. Particularly characteristic of the *Acanthaspids*, however, are the strongly developed immovable lateral spines, which are located on both sides of the anterior part of the body shield, behind the gill opening (fig. 8, A, B). If we view the anterior portion of the shield and the spines in cross-section it is not difficult to understand that we are here dealing with a genuine fold of the skin (fig. 8, A 4). It is therefore entirely natural that these spines should be regarded as homologous with the pectoral fins of other fishes. The spines are moreover not entirely horizontal, but their anterior edge is somewhat lower than their posterior edge, that is, they slant a little forward.

The posterior part of the trunk and the tail in the *Acanthaspids* was covered with rather solid scales as we can see quite distinctly from an almost complete specimen of *Acanthaspis* found in the German Lower Devonian and described by Broili (fig. 8, B). The same specimen also shows us that the *Acanthaspids* were without pelvic fins, and only had weakly developed medio-dorsal fins or spines. It is particularly noticeable that the caudal fin also seems to be lacking, as the body apparently simply tapers to a point. There can be no doubt that the *Acanthaspids* were typical bottom forms which swam very poorly. While swimming they used the posterior part of their trunk and the tail as organs of propulsion. The organs of equilibrium can be seen in their powerful spines and in their dorsal fins. Special steering organs in the form of movable paired fins are entirely absent. The spines probably not only served as organs of equilibrium but also as gliding organs in a similar manner as in the *Cephalaspids* and *Pteraspids* (figs. 2 and 7). *Acanthaspis* would rise from the bottom by powerful strokes of its tail, descending again more slowly, gliding on its spines.

The *Acanthaspids* disappear completely in the Middle Devonian, where they are replaced by a great number of other *Arthrodirans* showing the most diverse adaptations. Some adapted themselves more and more completely to a bottom mode of life, developing a rather flat head and body shield. Others, on the other hand, became free swimmers. A very well-known form from the Middle Devonian, *Coccosteus* (fig. 8, E; fig. 9, B), is fairly close to the *Acanthaspids*, but shows distinct adaptations to more efficient swim-

ming. The body is much higher, even though the ventral shield is still rather flat (fig. 9, B). The large spines are strongly reduced and can no longer serve as effective gliding surfaces. The posterior part of the trunk and the tail are, on the other hand, more strongly developed. The scales are entirely reduced and a solid calcified internal skeleton has been developed (fig. 9, E). From its structure we can conclude that the tail was still pointed and tapering, without special caudal fins, but *Coccosteus*, on the other hand, had a strong dorsal fin, an anal fin, and, besides, a set of pelvic ventral fins. In other words, *Coccosteus* has already developed, in addition

Un.Kl. Arthrodira

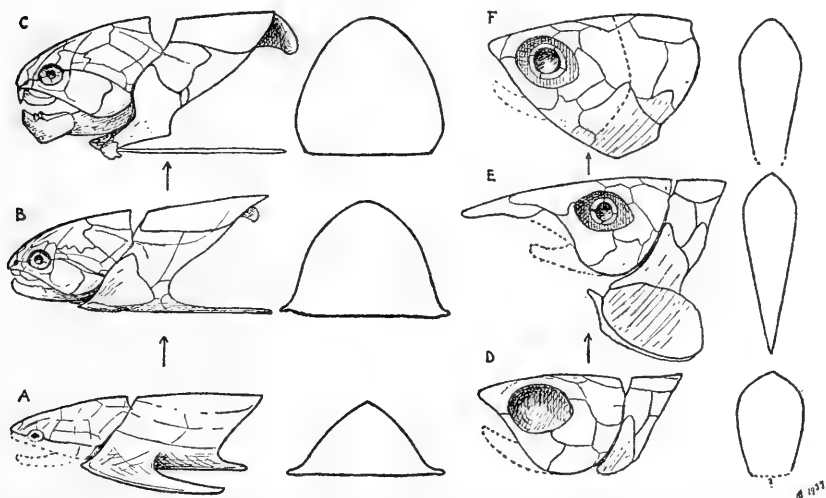


FIGURE 9.—Gradual evolution of Arthrodira from pure bottom forms to free-swimming representatives. A, *Acanthaspis*. B, *Coccosteus*. C, *Dinichthys*. D and E, flat, free-swimming forms from German Upper Devonian. F, *Solenosteus*, an Upper Devonian form in which the joint between the head and body has disappeared. (After Gross and Heintz.)

to the organs of equilibrium in the form of small lateral spines (homologous with the pectoral fins) and median fins, an efficient steering apparatus in the form of paired ventrals. Its entire shape also suggests that it must have been a better swimmer than *Acanthaspis*, in spite of the fact that it was still a characteristically bottom form.

The further evolution of the swimming Arthrodira goes in the direction of a more laterally compressed body and narrower ventral shield, and a more powerful development of the tail (fig. 9, A–E). Parallel with all these changes, corresponding entirely to what took place in the Ostracoderms, we also find a reduction of the thickness of the shield which in the youngest Upper Devonian forms has become paper-thin.

The last step in the adaptation to free-swimming is seen in a group from the Upper Devonian, in which the connecting joint between the head and body otherwise so characteristic of the Arthrodira has disappeared, and the head and body shields have become fused (fig. 9, F). The peculiar connection between head and body in the Arthrodira is practically unknown among fishes as it can only have served to interfere with the function of swimming. In the bottom-

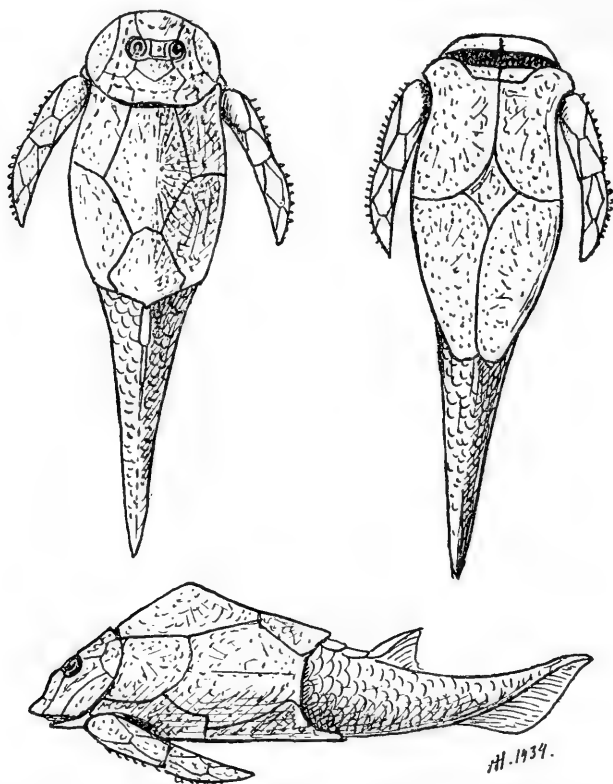


FIGURE 10.—A representative of the subclass Antiarchi (after Traquair). *Pterichtys* from the English Middle Devonian: Upper left, from above; upper right, from below; and lower figure, from the side.

living Arthrodira the head-body joint has been retained until the last Upper Devonian form, but in the more free-swimming representatives the head loses its separate mobility.

Thus we see how this group also, starting from typical bottom forms, gradually conquered the ocean and learned to swim.

The second group of the Placoderms (fig. 1) the so-called Antiarchi (fig. 10) are undoubtedly among the most peculiar beings which have ever inhabited the sea. In their strongly encased head and trunk they remind one a good deal of the Arthrodira. The head shield in these also is connected with the trunk shield through a joint (fig. 10).

We have here again a group of typical bottom forms, with a flat ventral shield and a strongly arched dorsal armature. The most peculiar feature is the development of the pectoral fins, which are modified into strongly reinforced spines (fig. 10). By means of a very complicated joint these spines are movably connected with the body shield. It is very tempting to regard these organs as a kind of oars by means of which the animals could swim through the water. This interpretation is rather improbable, however, as the connecting joint between the body and the spines is much too complex to permit any rapid motion, and the oars themselves are furthermore too thick and narrow and cannot be said to be in any manner an efficient type of swimming organ. On the other hand, they may very well have served as steering organs. The posterior part of the trunk and the tail were very short in the oldest form, and covered by scales. In the younger ones they were considerably longer and more slender and the scales were completely reduced. No Antiarchi show any perfect adaptation to free swimming. They all remained benthonic and only varied in their ability to lift themselves from the bottom.

I shall not attempt any detailed discussion of the two largest groups of fishes, the Elasmobranchs and the Teleostomes, which are the dominant forms in recent times. The Elasmobranchs are known as far back as from the upper Silurian, the first Crossopterygii were certainly from the Lower Devonian.

Even the oldest Teleostomes could in all probability swim relatively efficiently (fig. 11, A, D). The body was more or less oblong, and they had a large caudal fin as well as median and paired fins. I shall, however, not discuss their structure any further but shall proceed to another problem.

It is commonly acknowledged that the original or so-called primary form in fishes was more or less torpedolike, a form which is very well adapted for free-swimming in the water. The fishes have subsequently also adapted themselves, secondarily however, to other modes of life and have correspondingly modified their shape. Thus some of them have become flying fishes, others have changed to a bottom mode of life and some have become deep-sea fishes. Conditions are fairly clear insofar as we consider only the recent and the higher fossil Teleostomes. In these cases we can as a rule show that for instance the bottom forms have always been derived from free-swimming ancestors.

On the other hand, we have in the preceding considered a series of the old Paleozoic fishes and fishlike forms and know that they began from a bottom existence and only gradually learned to swim. We have seen that of a great number of Ostracoderms and Placoderms perhaps only a few, and then as a rule the youngest ones, can really be regarded as having been nectonic forms, that is, forms

which may spend their entire lives swimming around in the water without of necessity having to resort to the bottom.

Shall we now have to consider all these old Paleozoic forms as having been only secondarily benthonic? Do we really have to assume that they were derived from earlier free-swimming ancestors? To me the opposite thought seems much more natural, namely, that the oldest fishlike forms and fishes were primarily bottom-living.

We know very little about the ancestral forms of the vertebrates. But we may take for granted that they evolved in water. It is then also most natural to assume that the earliest, most primitive forms, lived on the bottom and had not yet specialized sufficiently to be able to swim. If the oldest vertebrates were bottom-living or perhaps even burrowing forms, they must have learned to swim just as they later had to learn to crawl, walk, run, and finally fly.

In my opinion the oldest known vertebrates, fishlike forms, and fishes, had not yet learned to swim, and we can in them observe the gradual transition from bottom-living to free-swimming forms. The clumsy forms with a large cephalothorax and a short thin tail, without organs of steering and balancing, could only move rather helplessly through the water and could scarcely lift themselves from the bottom (figs. 3, 5, 6). The further evolution went in the direction of the development of organs of equilibrium and of gliding surfaces in the form of more or less strongly developed spines or projections (fig. 3; fig. 7, A-E; fig. 8, A-D). The next step was the formation of effective steering organs in the form of movable paired fins (fig. 3, fig. 8, E). When all these technical difficulties had been overcome, the further modifications continued only in the direction of a more perfect adaptation of the entire body and of each separate organ to the function of swimming.

First of all, a gradual reduction of the heavy and thick external armature or scales took place, thereafter a modification in the shape of the body, and finally, a gradual perfection of the most important organ of propulsion, the caudal fin.

Parallel with these changes the inner skeleton also grew stronger and came to form a strong support for the greatly developed swimming musculature (fig. 12). We have seen the first step in this evolutionary series in the Ostracoderms and Placoderms. The well known evolutionary series of the Teleostomes show the subsequent steps very clearly (figs. 1, 11, and 12).

The oldest Devonian Crossopterygian (fig. 11, A; fig. 12, A) still have a comparatively plump body, and their large heads are covered by thick bony plates, their bodies by heavy scales. Their paired fins are brush-shaped and cannot be closely applied to the body, which fact serves to prevent very rapid swimming. Their heterocercal tail has a strong, scaly axis. They are fair but not yet

Ard. Teleostomi.

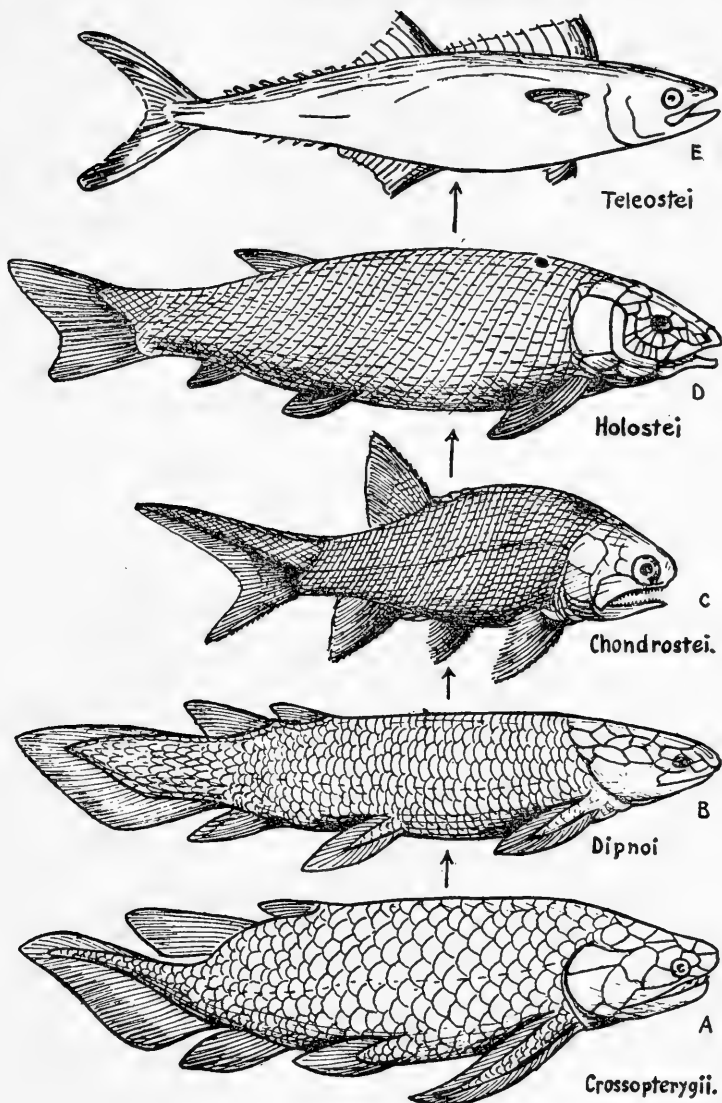


FIGURE 11.—Gradual evolution of different Teleostomes in the direction of better and better adaptations to swimming. A, a Crossopterygii (*Holoptychius*) from the Devonian; B, a Dipnoi (*Dipterus*) from the Devonian; C, a Chondrostei (*Amblypterus*) from the Permian; D, a Holostei (*Lepidotus*) from the Jurassic; E, a Teleostei, a recent mackerel. (Chiefly after Traquair and Woodward.)

very good swimmers and have in all probability preferred to live near the bottom. Their inner skeleton is weakly ossified. The same is also true of the Dipnoi (fig. 11, B, C, D, E; fig. 12, B, C, and D).

The Acanopterygii are already much better adapted to free swimming by the structure of their paired fins, which can be closely applied to the body. But in some of the oldest Chondrostei (fig. 11, C;

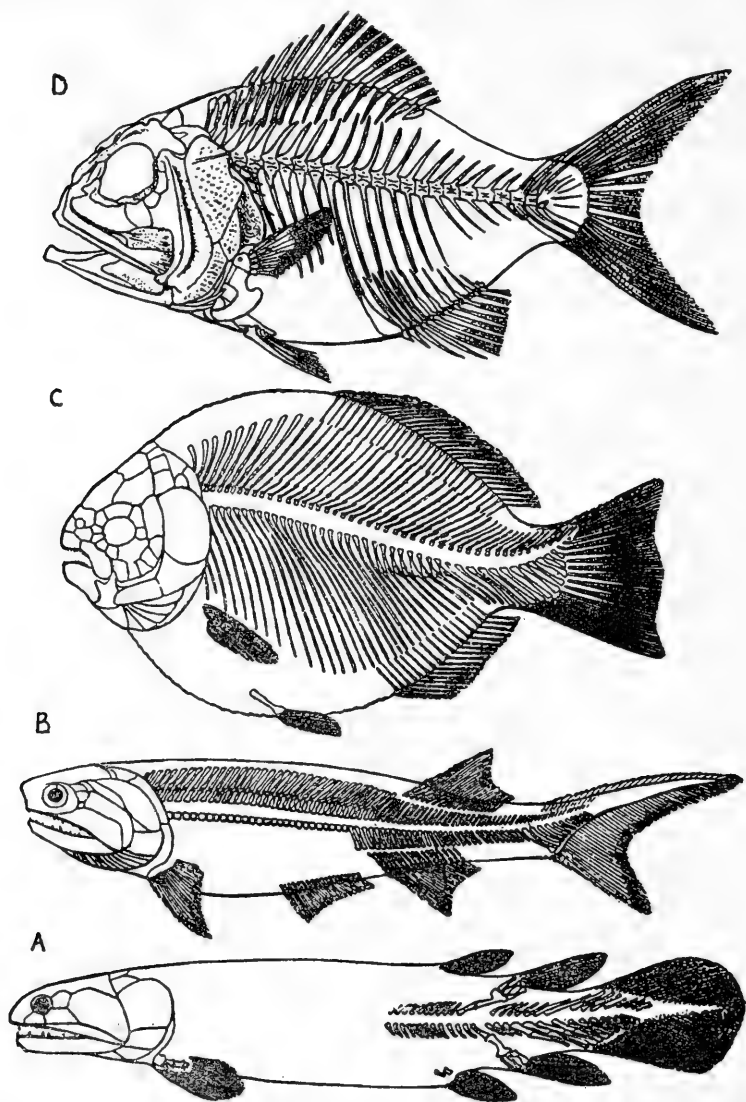


FIGURE 12.—Gradual evolution of ossification of the internal skeleton in different Teleostomi; A, in a Crossopterygii (*Thursius*) from the Devonian; B, in a Chondrostei (*Palaconiscus*) from the Permian; C, in a Holostei (*Dapedius*) from the Jurassic; D, in a Teleostei (*Hoplopteryx*) from the Tertiary. (After Woodward.)

fig. 12, B) which reach their greatest abundance in the younger Paleozoic, the inner skeleton is still weakly ossified and the body covered with thick, heavy, ganoid scales, and the tail heterocercal with a long, scaly axis running out into the upper lobe.

The next group, the Holostei (fig. 11, D; fig. 12, C), which abound in the Mesozoic, have still to a large extent preserved their ganoid scales, but the internal skeleton is much more strongly ossified and the tail has become almost entirely homocercal (evenlobed) as the scale-covered body axis in the upper lobe is strongly reduced.

Finally the recent Teleostei (fig. 11, E; fig. 12, D) have developed a completely ossified skeleton, and their scales are very thin and light, sometimes even completely absent, and their tails have become entirely homocercal. In these forms we therefore have the most perfect type of swimmers (fig. 2, A).

The evolutionary series here described is, of course, entirely diagrammatic. One cannot, of course, consider, for instance, the Ostracoderms or Placoderms as real and direct ancestors of the younger fishes.

But, as in numerous other series of comparable though not directly related evolutionary types, this series shows how the evolution in all probability has progressed, and how the different fundamental types have superseded each other. In general the evolution has proceeded parallel and independently within numerous different groups. In our schematic representation we therefore only bring together our examples of the different steps of evolution from the different lines which frequently developed quite independently of each other although on the same fundamental pattern.



CURIOUS AND BEAUTIFUL BIRDS OF CEYLON

By CASEY A. WOOD

[With 5 plates]

The island of Ceylon has for many centuries been known for its advanced ancient and medieval civilization, remains of which are everywhere visible. With this man-made condition and long antedating it are those natural wonders, its remarkable flora and fauna. In no other country are there found in so small an area such interesting and attractive mammals, reptiles (including snakes and crocodiles), birds, fishes, and insects. Botanically, also, the island is of outstanding importance, with a wealth of exotic plants, particularly the trees and shrubs, many of them bearing richly colored flowers, valuable fruits, and other useful products.

Geographically, the island is situated almost directly south of the Indian peninsula about 6° north of the Equator, with an extreme length of 270 miles and a greatest width of 137 miles. The country presents an almost unbroken covering of forests interspersed with over a thousand large and small artificial lakes, a central mountain zone, with a few peaks reaching 7,000 feet, and a dozen or more short but important rivers. Despite its large proportion of unsettled jungle and forest, there are many good motor roads giving access to all parts of the island.

Sinhalese birds number 371 species, of which about 52 are indigenous. As a modification of this statement it must be remembered that about two-thirds of the avian species found in Ceylon are known to breed or to have bred there, so that these may be regarded as residents. As Wait says, "Not counting about 20 species which may be classed as oceanic wanderers, roughly 125 forms, one-third of the total bird species, are wholly migrant. About 40 of these, however, have been recorded only on a few occasions, and less than one-half of the migrant total are really common and familiar birds. The percentage of migrants is far greater among Ceylon water birds than among the land species, while the general ratio of migrants to residents is far lower in this tropical island than in temperate regions."

The roster of Ceylonese birds includes numerous owls and hawks, and several eagles, although the last are of the smaller varieties and are rather rare. There is also a beautiful, distinct subspecies of the jungle-fowl. Rather abundant are the species and races of wild pigeons, parakeets, sunbirds, flycatchers, kingfishers, and orioles, most of them dressed in brilliant plumage. One might also mention crows (two species), toucans, the edible swift, partridge, snipe, and quail. Perhaps the most noteworthy of the avian fauna are the water birds and waders, among them many ducks, teal, flamingos, storks, egrets, ibises, herons, and spoonbills.

Bird protection through legislation and the fact that the majority of the inhabitants are Buddhists account for the great number, variety, and persistence of the avian population.

Some of the birds peculiar to the country¹ are of great interest and call for better colored portraits and plumage descriptions than this paper can furnish. One of these is a beautiful trogon (*Harpactes fasciatus* (Pennant)). It may be regarded as a subspecies of the bird found in South India where, as in Ceylon, it is seen only in thick and usually high forest. These birds are found in pairs; they are insectivorous, hawking their prey in the air, and their call note is a peculiar whistle. The accompanying plate (pl. 1, fig. 1) gives only a faint idea of this bird's brilliant plumage.

Another notable species is the small Ceylonese hornbill (*Tockus griseus gingalensis* (Shaw)), fairly common throughout the bush of the low country, where it is seen in the tops of the trees. Its call closely resembles a human laugh repeated with increasing harshness and frequency. Its food is fruit and large insects. It breeds from April to August and, following the rule of the genus, the female is walled up by means of a plaster of droppings in the nest, a tree cavity, by the male and is fed by him during the incubation period through a narrow opening in the covered retreat.

The races of babblers (most inappropriate name for birds that, whatever notes they emit, never "babble") are well represented in Ceylon, some of them being indigenous species. The brown-capped babbler (*Pellorneum fuscicapillum* (Blyth)) is a shy, skulking bird of the forest that builds a domed nest well hidden on the ground and whose call is a sharp whistle. The common babbler, a friendly bird, is nearly always found in flocks of from 5 to 7 and goes in Ceylon by the name of the "seven sisters." This company is probably made up of members of several families who flock together. I do not agree with Miss Kershaw as to the notes of *Turdoides griseus striatus* (seven sisters). My experience of this very common bird

¹ See Coloured Plates of the Birds of Ceylon, by G. M. Henry, Ceylon Government Printing Press, Colombo, 1927-30.

is that instead of being a "noisy bird, possessing a variety of screaming notes", these babblers have rather a subdued series of tinkling or piping calls that are rather agreeable than otherwise; a gentle, reedy note, quickly repeated, one might say. The scimitar babbler (*Pomatorhinus horsfieldi melanurus*) is well worth a brief mention. I have heard this bird in the Kandyan hills repeating (probably the male) something like this in deep, distinct tones—rather low, trilling, and liquid—"goo-goo-oo goo-goo-goo" about six times, much like the coppersmith in rate, except that its notes can be counted, whereas the coppersmith calls are too fast for numeration. Miss Kershaw says that when heard in early morning the male says "what-a-good boy, what-a-good-boy." The female ends her notes with "poor chick." Legge says the male call is a quick "wok-wok-ek-ek-wok"; the female a shorter call.

More beautiful than the foregoing, and peculiar to the island, is the black-capped bulbul (*Pycnonotus melanicterus* (Gmelin)), both sexes with bright orange markings. This species feeds largely on berries, has a length of 6.5 inches, and is everywhere seen. Another bulbul, and there are several of these species suggesting but having no real relation to the European nightingale, is the yellow-eared bulbul (*Kelaartia penicillata* (Blyth)), a rather tame bird frequenting inhabited areas and feeding mostly on fruits. It is slightly larger than the black-capped bulbul.

A curious representative of the drongos is the king-crow (*Dicrurus coerulescens leucopygialis* (Blyth)), a pugnacious, 9.5-inch species which rules the roost about inhabited houses and gardens and keeps the bird population, large and small, in regimented order. He hates and chases owls and woodpeckers and is something of a mimic. This white-vented drongo is in some districts called Kawudu-panikkiya or the "crows' barber"; in others, Kaputu-bena, the "crows' nephew." It is often seen chasing both gray and black crows, snatching feathers out of their plumage, especially from the head. The natives explain this vendetta by saying that in a previous birth the drongo was a barber and the crow a customer who failed to pay. In this incarnation he is not only being punished for his dishonesty, but the drongo is permitted to dun him for the arrears. The second synonym is explained by the fact that the drongo is so cunning that even his crafty uncle, the crow, was cheated by him. According to the folk-tale, the drongo challenged the crow to a high-flying contest, the challenge being accepted on condition that each should carry a certain-sized bag filled with any material he chose, and that the winner should, as his reward, be at liberty to knock the loser on the head. The crow craftily chose cotton, the drongo, weatherwise, filled his bag with salt. They had not soared far before it began to rain in

torrents; the crow's bag absorbed and retained the water and, of course, got continually heavier, the drongo's load became continually lighter owing to the washing away of the salt, and before long he had nothing to carry. The drongo won, and has ever since exercised his privilege of pecking at the crow's head.

The racket-tailed drongo (*Dissemurus paradiseus ceylonensis* Sharpe) is much more striking (see pl. 3, fig. 1) in appearance than the foregoing, although by no means more interesting in its habits.

The genus that includes the barbets has always been of great interest to me. These remote allies of our woodpeckers excavate a nesting hole in some soft wood or decayed tree, often near a human habitation, and make no effort to conceal themselves or their works. The Indian crimson-breasted barbet (*Xantholaema haemacephala indica*) is represented on the island by the small Ceylon barbet. The local name of this very common bird is the coppersmith, and whoever has listened to its pneumatic-hammer call (so rapid are the strokes that they cannot be counted) will consider it an appropriate title. The Ceylon green barbet (*Thereiceryx zeylanicus zeylanicus*) is another interesting species. At any time of day can be heard the loud call of this bird—"mo-hawk, mo-hawk"—3 or 4 times repeated, the accent being always decidedly on the second syllable. Sometimes the notes will be kept up at short intervals for an hour, thus earning for the bird the (local) title of "brain-fever bird". The first or introductory notes are sometimes slurred.

The kingfisher in one form or other is almost cosmopolitan; it is found all over the world, from the large laughing jackass of Australia to the pigmy species of South America and elsewhere. Although they generally feed on fish alone, their food sometimes includes large insects, small reptiles and amphibia. The Ceylon species are remarkably beautiful and possess peculiar habits. If we are to believe the evidence of the drongo's attitude toward Sinhalese kingfishers, the latter are not guiltless of occasionally stealing the nestlings of other birds.

To me the most interesting species is the pied kingfisher of Ceylon and India (*Ceryle varia*). Instead of darting on its finny prey from the branch of a tree or other perch, this black and white bird flutters over the water, like a kestrel or a hummingbird, watching for fish. I have often observed this curious kingfisher, poised in air, turning his head from side to side searching the water beneath him until, his fish in view, he made a sudden plunge and rose with the catch in his mandibles.

Of the lovely parrakeets, both indigenous and migratory, that belong to the Sinhalese list, one may remark that these birds cannot in Ceylon (or elsewhere, for that matter) be poked, pulled, snared, or smoked out of their arboreal holes without killing or irreparably

injuring them. In vain does one hammer on the tree or shout down the nest aperture. The parrot knows he or she is safe and inaccessible and simply lies "doggo". Wait has well described the native Sinhalese method, an ingenious and humane one, of capturing parrots, both nestlings and adult birds. It is practically impossible by ordinary means to dislodge these birds from the deep holes in hardwood trees which they generally choose as a refuge from various enemies, and where they may raise a brood in peace and quiet. The fledglings are generally two, although most Ceylon parrakeets lay three or four eggs to the clutch. As a rule, the hole is too small and too long and deep, like a woodpecker's nest, to be reached by any native arm however long and skinny, not to mention the strong, curved beak and needle-pointed claws that are waiting for invaders from above. I have already described elsewhere my adventure on a Pacific island when, with native assistance, I tried to examine the nest of a Polynesian parrot, whose nesting activities had never before been described. On that occasion we did not wish or try to capture the mother parrot who was sitting on her two eggs secure from interruption at the bottom of a 4-foot hole in the stump of a tree that was as hard as any oak. There she was, and there she stayed, quite unaffected by any efforts of ours to dislodge her, and we were obliged eventually to hack through the base of the stump before she could be dragged, with some inconvenience to herself, from her hiding place. The only damage done was to the Kandavan who, with his big chopping knife, had acted as excavator. He received several deep scratches and one vigorous bite that cost me half a tin of cigarettes.

The Sinhalese resort to no such crude methods. When a parrot's nesting pocket is discovered, the natives keep watch of it, and when, from various signs, the occupants are believed to have arrived at a suitable age for caged life, the Sinhalese boy shins up the tree in a trice and, standing on a nearby branch or simply clasping the trunk of the bole holding the nesthole, dislodges the birds without trouble. It is a triumph of brains over brute force. There is no laborious cutting away of the wall of the nesthole, with its possible danger of injuring or (almost as bad) frightening the birds half to death and thus lessening their value either as human companions or as a commercial commodity. From the native's neck is suspended a bag filled with dry sand. From this he takes a handful and carefully, a little at a time, pushes it into the hole. The sand falls on the parrots' backs. They shake it off and trample it under foot. The operation is repeated—remember that time is of no importance to the Sinhalese, who is engaged in a task of his own choosing—until the birds gradually elevate themselves to the top of their excavated nest. A prac-

ticed grasp of the now exposed bird, with perhaps a bite or scratch or two (if the adult bird is at home) and the family are thrust, without the loss of a feather, into an empty sack.

It is by this means that the charming little indigenous parrot, Layard's paroquet (*Psittacula calthrapae* (Layard)) is captured. It is a beautiful forest and hill species, sometimes found about villages and paddy fields, its eggs being laid in a hole high up in a dead coconut palm or other tall tree. Another lovely little parrot, the common Ceylon loriquet (*Coryllis beryllinus* (Foster)) is found in almost any low country jungle or native garden. It has a voracious appetite and is fond of drinking the toddy from the pots in which it is being collected—a regular avian toper. The eggs, laid in some natural cavity of a tree, are deposited in a nest made of green leaves.

In two of his 555 reincarnations Buddha was a parrot, an honor that conferred upon the genus the power of speech. The Sinhalese have a number of sayings about this interesting order. For example: "When the cat mews the parrot's 18 languages come to an end." "Though the cage be made of gold, the parrot prefers a roost in the forest." "As ungrateful as a parrot", who may bite his best friend. "This fellow is like a parrot"—a chatterer or a mere imitator.

The red-wattled lapwing is to the Sinhalese the type of watchfulness and faithfulness to its offspring. At all hours, day and night, when its nest is approached it rises with a shrill cry. It is believed by the natives that the eggs, eaten raw, will drive away sleep and induce watchfulness. It is also asserted by them that the lapwing lies on its back in its nest with its legs upward to keep its eggs from being crushed should the sky fall. Jerdon notes the same belief in South India. A Sinhalese proverb says that "truly pious and revered priests are those who observe their religious vows as assiduously as the kirala (lapwing) guards her eggs, the samara (deer) his tail, the father his only son, and the man with but one eye the remaining organ." In one of the early Buddhistic manuscripts occurs the following: "She who has become pure in mind and body observes on poya days the eight rites and every day the five rites as (faithfully as) the kirala guards her eggs and the samara his tail."—(Nell.)

The Ceylon crows, both the common gray variety and the jungle crow, are intelligent thieves, the former with a marked predilection for stray golf balls. These birds have many sayings attributed to them by the Sinhalese. The native name, Kakka kaputa, is interpreted to mean "I eat everybody (everything), but nobody eats me." "A cunning man's look is like that of a crow." "There is no place

that the Moorman [not much liked by the aboriginal Sinhalese] and the crow are not found." "The crow also said, 'It is bad to play with bows and arrows.'" As showing his ingratitude, "The peacocks gave shelter to a crow who, in return for their hospitality, showed a hunter the way to their roost." As to his insatiable appetite and greed, "Even in the three watches of the night he is faint for want of food." "Only when he swallows a rag dipped in ghee [liquid butter] will the crow feel full."—(Nell.)

The Ceylon magpie robin (*Copsychus saularis ceylonensis*), the coconut bird or the dawn bird, is heard in the early morning and evening. It has a song clear and sweet, although less melodious during the day, when it seems to repeat "miyachchi", or "dead", and hence is regarded as a bird of ill omen. The call is said to announce evil tidings. It is believed by the Hindus to be the incarnation of Huniyan-yaka, bringing misfortune to the healthy and death to the sick, and the villagers pelt it with stones to drive it away from their dwellings. If this bird builds a nest in a cabin, it is thought to be a great misfortune.—(Nell.)

The Sinhalese explain the sorrowful note of the Ceylon spotted or ash dove as follows: A woman placed some kebella berries in the sun to dry and told her son to watch them carefully while she was away gathering firewood. As they dried they stuck to the ground so that they could barely be seen, and on her return she accused the boy of eating the fruit, and in her rage she struck and unfortunately killed him. She then in remorse killed herself and was transformed into a spotted dove, and she now flies through the forest mourning her lost son with the well-known cry of "pubbaru puta pu pu" or "Oh! my young son."

The black patch on the throat of the male Indian house sparrow is, according to the legend, due to fire in a house where a pair had a nest. The hen flew away, but the cock battled bravely through the flames to rescue his young in the nest beneath the eaves. He scorched his throat and the mark still remains to testify to his bravery and paternal love. The building of a nest and breeding by sparrows in a house is considered a good omen, and to encourage them in this, chatties (earthen bowls) are often hung on the walls. If a sparrow makes a nest and rears her young in the house, the next child born to the owner will be a boy. Sparrows' eggs broken and accompanied by proper incantations make a charm to stop an objectionable tomtom by causing the collapse of the instrument. The shell reduced to powder, placed on a betel leaf, and mixed with certain other ingredients makes a potent love philter.

Ceylon is abundantly supplied with interesting flycatchers of all sizes and colors. The beautiful paradise flycatcher is called by the

Sinhalese gini-hora (fire-thief) and kapu- or redi-hora, the former name from the fact that in his rapid flight through the forest his long, streaming tail feathers give this bird the appearance (in the younger or red phase) of flying about with a firebrand; in the (male) white or maturer state, he has the appearance of carrying off a bunch of cotton, hence his local name of "cotton-thief." The long tail feathers form a prominent character of this attractive bird.

The fan-tailed flycatcher reminds me both in appearance and habits of flight of the lovely New Zealand bird. It is a small (well-mixed) black and white species that tosses and tumbles through the air in pursuit of its insect prey while it repeats its song or call note, which translated into English is said to be "Why don't you pick the peaches quick?"—or by the more practical observer, "Whisky, gin, and bitters." It is by the latter phrase that this attractive species is most commonly known in Ceylon.

A beautiful little blue and brown flycatcher, peculiar to the island, was first described by the American ornithologist, Oberholser—*Cyornis tickelliae nesaea* Oberholser.

There are several so-called and well-known Ceylon "robins", among them the very pretty black robin and the still more attractive magpie robin, just mentioned. Another rarer variety, the pretty little Indian red-breasted flycatcher, goes by the vernacular title of the hill robin. I need not add that none of these birds is even remotely related to either the English robin redbreast or to our own American robin.

One of the most curious of the indigenous birds of Ceylon is the red-faced malkoha (*Phoenicophæa pyrrhocephalus* (Pennant)) that may be described as a mixture of cuckoo and magpie. It is a shy and rare bird (length, 18 inches; tail, 11 inches), living mostly on berries and inhabiting only the highest tree tops of the deep jungle. This species early attracted the attention of visitors and was described by Forster in 1781.

The Ceylon iora (peculiar to the country) is another beautiful bird, like a small oriole, with its attractive black and orange markings. It generally occurs in pairs, inhabiting gardens and the leafy jungle. The male has a clear, sweet whistle of two notes; the nest is an artistic little cup bound to the bough or fork of a tree by cobwebs. Its systematic name is *Aegithina tiphia zeylonica* (Gmelin), a long cognomen for such a small and dainty bird.

Ceylon possesses several woodpeckers, some of them peculiar to the island. The pygmy (length 4.8 inches) is found nowhere else. It is a charming, dark brown, whitish-spotted bird. There is an odd Sinhalese folk-tale about the woodpecker. Once upon a time there was a korowaka (rail) who sold areca nuts. One day he flew to his

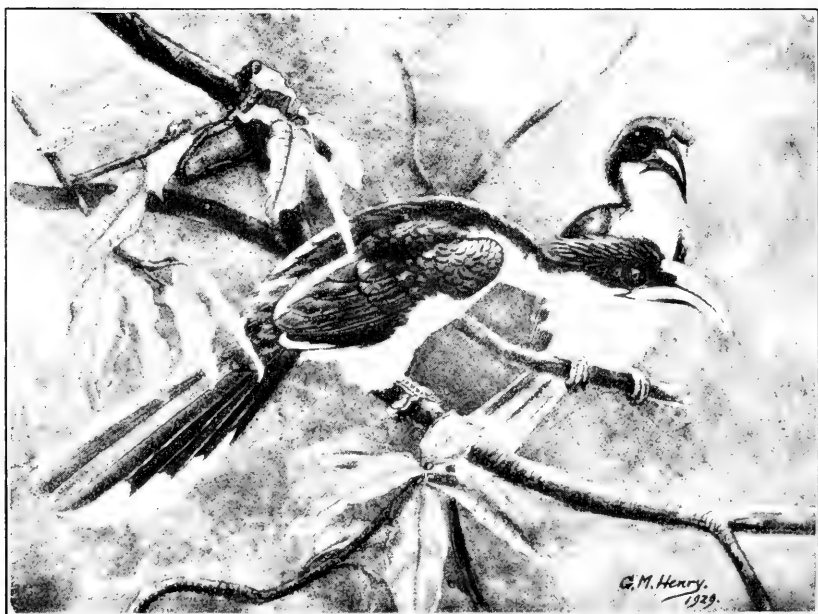
uncle's at Velikilla, obtained a supply of nuts, hired some geese to carry the heavy bags to the waterside and there embarked with them in the keralla's (woodpecker's) boat. The overloaded boat capsized and both boat and nuts were lost. When the two birds reached the shore, the waterfowl abused the woodpecker for shipping his property on such a shaky old boat. "But what", replied the woodpecker, "is your loss to mine? There are plenty of areca nuts, but where shall I find another such boat?" And so the woodpecker wanders about the world, tapping the trunks of trees, vainly seeking pieces of wood large enough to build another boat. The waterfowl still walks by the waterside crying "kapparakata puwak puwak" (a vessel full of areca nuts, areca nuts). That the geese also suffered is proved by looking at their deformed necks, bent and crooked from carrying heavy bags of nuts.

There are a number of beautiful wild pigeons in Ceylon, among them the pompadour green pigeon (*Treron p. pompadoura*) that, by the way, has no cooing call, but a distinct whistle. This beautiful bird is an indigenous species, abundant all over the country. An even more lovely species is the Ceylon green imperial pigeon (*Muscadivores aenea pudilla*), whose call is a distinct double "coo-cooque." This bird is 16 inches long and presents an unusual display of color.

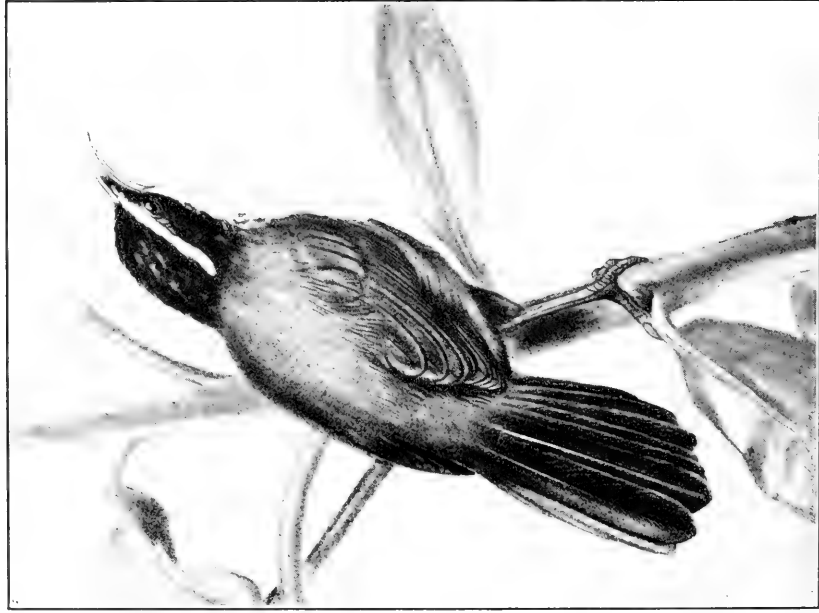
I have made reference in several previous papers to that wonderful nest builder, the Indian tailor bird (*Orthotomus s. sutorius*), a common resident of Ceylon. Since then I have received from the island a number of other examples of the fine sewing, stitching, and suturing these little birds are capable of. I must once more emphasize here that, unlike those of certain nest-making ants, the stitches used by the tailor bird in sewing together so effectively the edges of a leaf or leaves are continuous, just like the plain sewing of the human seamstress. The cornucopia-like nest, which she afterward lines with all sorts of fibers, grass, moss, and cotton, although of delicate structure, often withstands the winds and rains of several seasons.



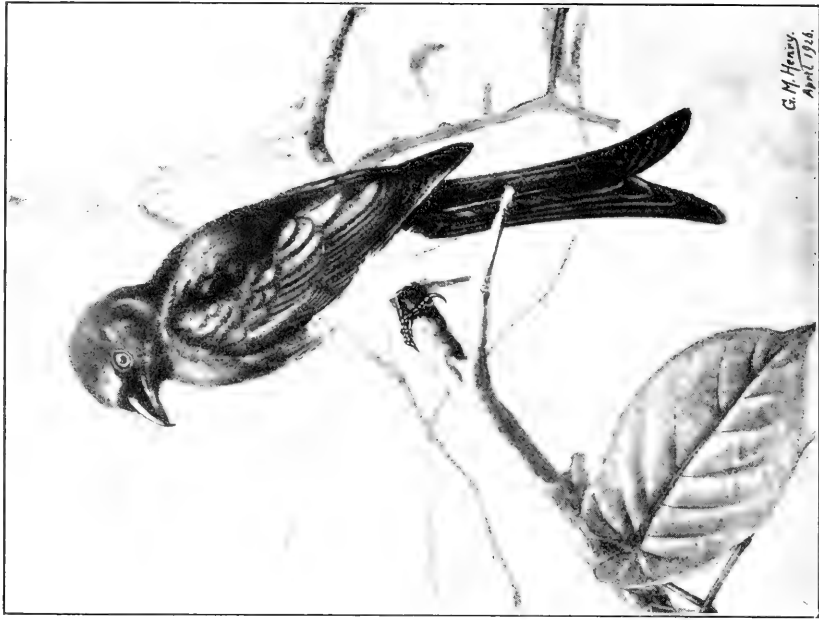
1. THE CEYLON TROGON.



2. THE CEYLON GRAY HORNBILL.

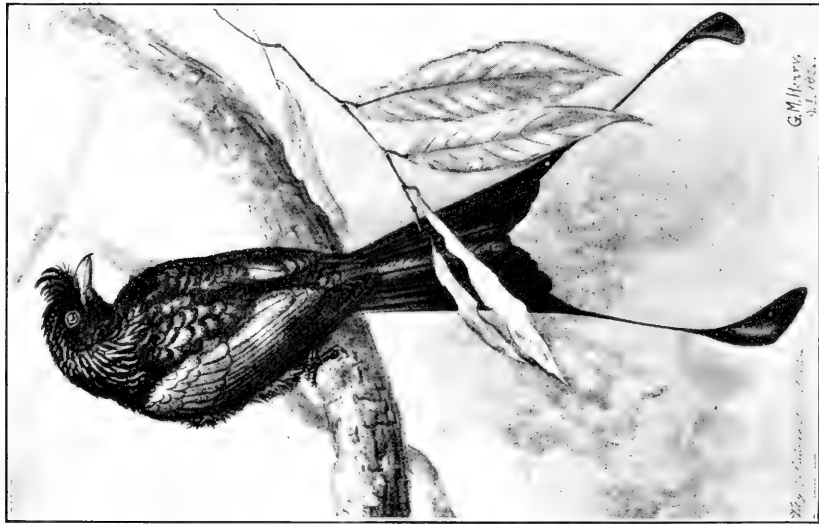


1. THE CEYLON SCIMITAR BABBLER.

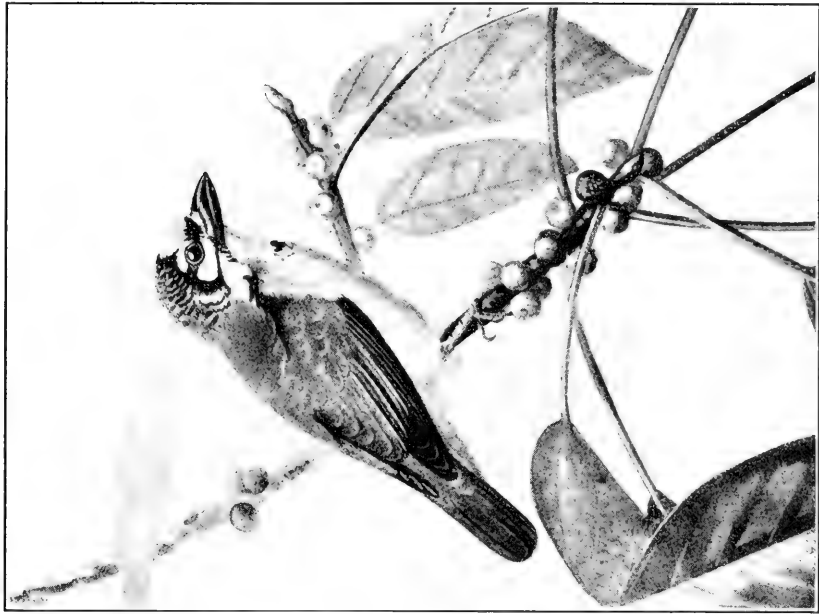


G. M. Henry,
April 1924.

2. THE WHITE-VENTED DRONGO.



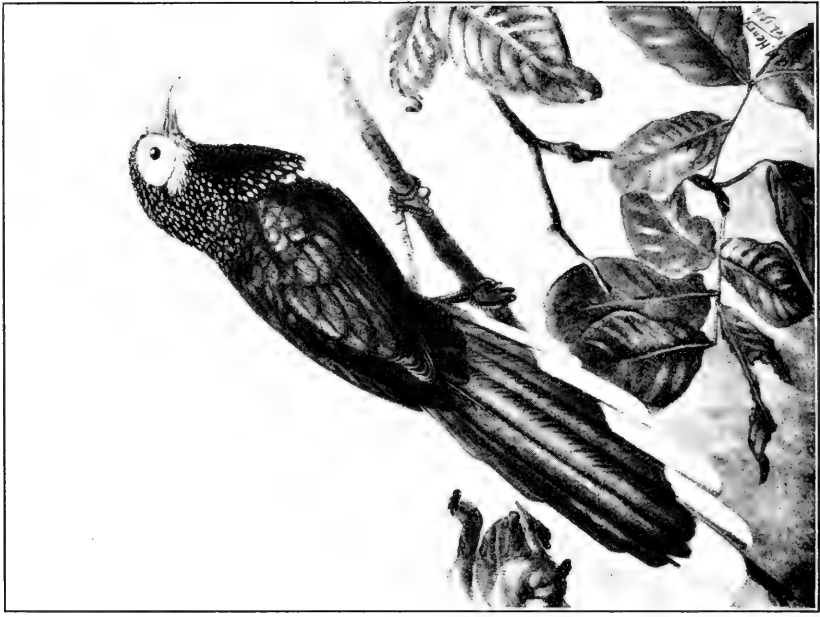
1. THE CEYLON RACKET-TAILED DRONGO.



2. THE SMALL CEYLON BARBET.



1. OBERHOLSER'S BLUE FLYCATCHER.



2. THE RED-FACED MALKOHA.



1. THE CEYLON IORA.



2. THE CEYLON PYGMY WOODPECKER.



THE INFLUENCE OF CIVILIZATION ON THE INSECT FAUNA IN CULTIVATED AREAS OF NORTH AMERICA¹

By ROGER C. SMITH

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The most striking characteristic of present day civilization is change. Nothing remains stationary or unchanged in the march called progress. Man has taken literally the task of transforming the face of the earth. As a result of his efforts, plant and animal life have been as strikingly affected as the fields and plains. He has, in a large measure, disdained nature's crops and planted crops of his own choosing. Since animals as a group largely depend on plants for food, as the flora changed the fauna followed suit. Man has upset the ancient balance in the cultivated areas, and agriculture and biological conditions have been kept in such a turmoil of change that no new balance has been yet set up.²

By cultivated areas is meant the farms and gardens, the transformed hillsides, valleys, and plains. The transformation has been a replacement of a sod containing many species of plants to a more or less pure culture of one plant. There is also a marked tendency towards specialization of crops involving large acreages in the cultivated areas of North America. Our attention turns quickly to definite, more or less circumscribed regions, when the following crops are mentioned: Wheat, corn, cotton, citrus, sugar cane, sugar beets, apples, peaches, plums, blueberries, dates, and celery. This specialization tends to upset the balance even more completely than if the crops were generally diversified.

Plowing up the native sod, clearing the forests, and watering the desert affected markedly the insect fauna of the region. The climate, meteorologists claim, has not been appreciably affected by these activities, but soil climate has been markedly affected. So the greatest factor has been the change in food plants for the hosts of insects.

¹ Contribution no. 404 from the Department of Entomology. Reprinted by permission from *Annals of the Entomological Society of America*, vol. 26, no. 3, September 1933.

² Smith, Roger C. Upsetting the balance of nature, with especial reference to Kansas and the great plains. *Science*, vol. 75, pp. 649-654, 1932.

DECREASE IN CERTAIN SPECIES OF INSECTS

Some insects are less plentiful now because of these agricultural activities and because of the incidents connected with the progress of civilization. The periodical cicada has been adversely affected by civilization. The great swarms rending the air with their shrill music and causing bushes to bend under their weight will before many generations exist only in story. Bumblebee nests are much less frequently encountered during ordinary farm operations than was the case 30 years ago. Civilization has been unfavorable to bumblebees and to field mice whose nests are often used by the bumblebees for making their nests. Outbreaks of grasshoppers are becoming less frequent in Kansas because of improvements in control measures and of decreasing areas of suitable breeding places. Grasshopper outbreaks are not characteristic of areas of intense cultivation on small farms and gardens.

Such insects as the spring canker worm, which 30 or 40 years ago defoliated orchard and shade trees almost unchecked, have been reduced by spraying for the codling moth, a more serious and more recent pest. Likewise, dusting cotton for the cotton boll weevil has relegated the less serious pest, the leafworm, to a minor place in some of the cotton-growing areas. Thus artificial control measures for the more serious pests have reduced some secondary ones also.

Invention even enters in here, for collectors of dung beetles say that some species of this group of Scarabs are not so easy to collect since the decrease in the use of horses in transportation. One wonders, when he sees radiators of automobiles plastered with insects, especially butterflies, dragonflies, and grasshoppers, whether this device of modern civilization might not become a more important factor in the reduction of populations, both insect and vertebrate.³

Sanitary and health measures have brought about a probable reduction in many forms of importance in the field of medical entomology. Extensive paving of roads and streets, river improvements, better drainage on farms and cities, together with the extensive propaganda about mosquito-borne diseases, have kept down mosquitoes, particularly in cities, except for sudden increases following periods of heavy rains. The great reduction of horses in cities has reduced fly-breeding opportunities. The widespread understanding of food contamination has placed the typhoid fly on the public enemy list.

Parasitic forms dependent on wild animals become less plentiful as their hosts decrease, unless they select new ones. The hippoboscids

³ Fernald, H. T. Automobile as an insect collector. Bull. Brooklyn Ent. Soc., vol. 26, no. 5, pp. 231-233, 1931.

(*Lipoptena depressa*) and the head maggot (*Cephenemyia* sp.) of deer may be cited as examples.

SOME SPECIES OF INSECTS HAVE INCREASED IN NUMBERS

It is easier to cite examples of forms which have increased as a consequence of the activities of civilization. In the days of the old prairie, many species of insects subsisted on the perennial grasses, but the food supply was not abundant enough to permit the great increase of any one species.⁴ Under farming conditions there is no longer a great number of species generally intermixed, but a few species present, sometimes in very large numbers, in the almost pure stand of some crop. A very large group of insects has adopted as food plants these new crops which have partly replaced the primitive flora. When the potato was brought to North America and was carried to the home of the Colorado potato beetle, there was provided a real opportunity for expansion for these insects. The potato, being a member of the same plant genus as the beetle's native food plant, the buffalo bur, was promptly accepted, and between 1824 and 1893 the beetle had attacked the introduced potato plant from the Gulf States to Canada. This potato beetle has accepted the eggplant and, less commonly, the tomato, peppers, and tobacco for food plants also, all of which belong to the nightshade family.

The chinch bug, a native feeder on some wild grasses of the great plains, did not become plentiful until acres of corn, oats, wheat, and grain sorghums were provided by modern agriculture. The corn ear worm must have had a discouraging time, if one can judge by present field conditions, before corn, cotton, tomatoes, and the rest of its adopted food plants were made available by civilization.

The Hessian fly bred on some ancestor of modern wheat, or on other wild grasses, including wild rye, before civilization provided acres of wheat for it to feed upon. In North America, it has never been abundant except on wheat, barley, and rye, but it is known to run its life cycle in small numbers interchangeably with certain wild grasses, particularly of the genera *Agropyron* and *Elymus*.⁵ While in its native European home the Hessian fly had only one or two generations a year, in the central part of the United States it could generally have three generations a year, and sometimes in southern Nebraska, most of Kansas, and northern Oklahoma, it could have four or five generations. This indicates how much more favorable the climate and food conditions are in its adopted country.

⁴ Metcalf, C. L., and Flint, W. P. Fundamentals of insect life, pp. 412-416. New York, McGraw-Hill, 1932.

⁵ Noble, W. B. Two wild grasses as hosts of the Hessian fly. Journ. Agr. Res., vol. 42, no. 9, pp. 589-592, 1931.

Most of the grass-feeding forms still retain their original food plants and habitat while reaching out to conquer new worlds. The grass-feeding cutworms and wireworms often occur on crops in outbreak proportions, particularly on wheat, corn, and alfalfa. Small armyworms are said to overwinter in grass plots. The fall armyworm often appears in numbers in bentgrass lawns or plots before it does in wheat or alfalfa. The army cutworm, the greasy and well-marked cutworms, when scarce, can often be collected to best advantage in grass lands, under stones, boards, or trash. Likewise, certain species of wireworms occur in similar locations, especially in the early spring. It is but a short step from the wild grasses to the cultivated ones, such as corn, wheat, sorghums, etc. White grubs are worst in grassy fields or gardens. It is but a short step from feeding on the roots of lawn and pasture grasses to strawberries, potatoes, corn, and many other crops.

The wheat stem maggot (*Meromyza americana* Fitch.) has shifted from wild grasses to wheat and has found the change advantageous. False wireworm larvae formerly fed on weed seeds and decaying vegetable matter on or under the surface of the soil in the Great Plains region. It was a logical move to feeding on the kernels of fall-sown wheat in the drier portion of the Great Plains States when germination was delayed.

The mole crickets, normally satisfied with the roots of grasses, damage potatoes in the Gulf States, while the Puerto Rican mole crickets, lifting the soil around young celery plants in Florida, have become major enemies to the celery growers.

The tile-horned Prionus (*Prionus imbricornis* Linn.), a native insect feeding among the roots of big bluestem grass, has lately been found to be a serious apple-tree pest in Arkansas.

The harlequin cabbage bugs, striped cucumber beetles, melon aphids, and tarnished plant bugs all find food plants more diverse and favorable as a result of modern agriculture, and are probably more plentiful as a result of it.

Termites probably were natural feeders on sod, shrub, and forest remains before civilization provided houses with the attractive oak and hard pine floors. In their former role, termites were nature's aids in the return of humus to the soil. Now they are aids chiefly to carpenters and lumber dealers by making rebuilding and repairing necessary.

The shift from wild food plants to cultivated ones is most marked among fruit insects.⁶ From wild plum came the plum curculio and the peach-tree borer; from hawthorne the apple maggot, the lesser

⁶ Herrick, Glenn W. Manual of injurious insects, p. 18. Henry Holt, 1925.

apple worm, and quince curculio; from wild crab came the round-headed apple tree borer and the light apple redbug. These forms thrive among the acres of plum, cherry, prune, and apple orchards developed as a consequence of modern agriculture.

Apparently the famous blueberry of the maritime provinces of Canada and New England has an increasing list of insect enemies. This plant, largely uncultivated, forms the basis of a million-dollar industry in Maine. A recent study of this plant added, over the lists of previous writers, 80 insect pests depending on the blueberry for food.⁷

The apple curculio (*Tachypterellus quadrigibbus* Say), a native insect which fed on hawthorne and wild crabs, has lately become a severe pest of apples in northeast Kansas, and the greater the neglect or poorer the orchard sanitation, the worse the damage. Another species of this genus has lately been noted to be a cherry pest in Colorado.⁸

The walnut husk maggots (*Rhagoletis juglandis* Cress.) were until recently innocuous dwellers under the hulls of the common black walnut and a few other similar hosts. While they still occur on their wild hosts, these insects in recent years have appeared in Arizona and California, where they have produced a problem for the English walnut growers. As a result of their feeding in the hulls of English walnuts, the nuts are stained and rendered less marketable.

The plum gouger was an unimportant feeder on wild plums, but has increased under modern orchard conditions. The grape berry moth, grape flea beetle, and the grape root worm, all of which fed on wild grapes, have found expansive opportunities very favorable in modern vineyards.

The beet leafhopper, during the summer, forsakes its wild food plants in the foothills or desert for the beet fields. After spreading havoc in the beet fields, some of these insects return to their wild food plants in the foothills. A recent increase in curlytop damage to beets in Utah is said to be due to new breeding grounds of favorable host plants on thousands of acres of abandoned dry farms.⁹ This situation raises the question of what will happen when man begins to abandon agricultural lands if the soils are depleted or the price of the products makes their continued cultivation unprofitable. Such pests as the beet leafhopper and grasshoppers are likely to be favored by that step.

⁷ Phipps, C. R. Blueberry and huckleberry insects. Maine Agr. Exp. Sta. Bull. 356, pp. 107-232, figs. 17-24, 1930.

⁸ List, Geo. M. A cherry pest in Colorado. Colorado Agr. Exp. Sta. Bull. 385, 106 pp., 1932.

⁹ Knowlton, Geo. F. The beet leafhopper in northern Utah. Utah Agr. Exp. Sta. Tech. Bull. 234, 64 pp., 1932.

INCREASE DUE TO IMPORTATION

A glance at the extensive list of injurious insects in North America which have been introduced, impresses one with the importance of this heading.¹⁰ Thirty-seven out of 73 of our most injurious pests have been imported from other countries. More recent introductions include the Japanese beetle, European corn borer, pink boll worm, oriental fruit moth, European elm scale, and the lesser corn stalk borer. All of these are in the stage of dispersion at the present time. Many others, kept out by determined vigilance, are intercepted every year by quarantine inspectors at ports of entry.

THE INTRODUCTION OR DEVELOPMENT OF NEW CROPS

The introduction of new crops to North America has resulted in the pests of the crop following close behind. The semitropical crop of cotton, fed upon by the Mexican cotton-boll weevil, is now attacked by this insect over nearly the whole of the cotton belt, even when grown well northward in the temperate region. Citrus pests followed the introduction and extensive development of citrus fruits in Florida, Texas, and California. Each of the three districts has a somewhat different coterie of pests with which to contend.

The areas for growing Sudan grass have been limited largely by the chinch bug. Sweet corn is attacked too severely in the subtropical regions by the corn-ear worm, the armyworm, and other pests to be a commercial possibility.

There has been a marked increase in the number and destructiveness of pests of pecans attacking the trees or nuts of this relatively new crop. Many of the pests have transferred from other trees, especially hickory, black walnut, oak, and similar nut-bearing trees. Some of the worst enemies have not spread as yet throughout all the pecan-growing regions.

The changing status of the insect pests of farm legumes and the shift to the new hosts as they increased in acreage is a situation sufficiently recent for present-day entomologists to have observed. Crimson clover was the first legume to be used extensively as a hay and soil-building crop. Then, about 60 years ago, alfalfa was introduced. This crop was relatively free of insect damage until about 20 years ago when the clover insects had so thoroughly adopted it that insect damage became a grower's problem. Then came winter vetch and sweet clover, which the alfalfa insects rather promptly adopted. Cow peas and soy beans are also attacked by some of the old clover insects. Lespedeza shows no insect damage in Kansas so far, but the clover or alfalfa insects will no doubt in time adopt it as a food

¹⁰ Herrick, Glenn W. Manual of injurious insects, pp. 16-17. Henry Holt, 1925,

plant. A similar trend is shown in the shift of grass insects to corn and to the many kinds of feterita and sorghums. The papaya, avocado, date palm, and similar lately commercialized fruits in the United States, not yet severely attacked, may be expected to serve as hosts to some serious insect pests before many years.

The introduction of new crops into North America is likely to continue indefinitely. These new crops probably will be free of severe insect damage at first, but soon pests, by transfer or importation, will harass them. This has been the course of events in the past. It will be interesting to observe the building up of the list of pests of such new crops as the tung-oil tree in Florida, and the pineapple in the West Indies, lespedeza and the Chinese elm in the Great Plains.

INFLUENCE OF MODERN TRANSPORTATION

In the last century, civilization has become increasingly in a hurry to go places. Consequently, means of transportation have become more varied and speedy. The excellent transportation facilities provided since the first railroad in 1829 have been a great aid to insects in extending their domain. Gypsy and brown-tail moth larvae have been noted to drop on automobiles and be whisked off to new feeding grounds. Egg masses of the gypsy moth were shipped to Cleveland from New England on stone intended for building construction. Quarantine officers during the summer stop automobiles in certain sections in search of European corn borer stowaways on green corn. The possibility of importing, in airplanes, infected yellow fever or malarial mosquitoes from Central American countries to the shores of the United States has received consideration. Likewise, the danger of spreading the West Indian, Mexican, and the Mediterranean fruit flies in fruits carried by passengers who may discard them, innocent of possible consequences, has been pointed out repeatedly. So by railroad, steamboat, automobile, airplane, zeppelin, and all other transportation devices, insects spread their ravages much faster than by the legs and wings provided by Mother Nature.

PHYSIOLOGICAL STRAINS OR VARIETIES

Plant breeding and exploration have resulted in great assemblages of not only many kinds of plants, but also of many strains of these plants. One needs only to think of the many kinds of apples, peaches, plums, and cherries; of the many kinds of wheat, corn, grain sorghums, and of most every other variety of crop grown. It has been found that there are different strains of the insects, which strains are geographically distributed according to the crop.

The blueberry maggot is an example of incipient species formation.¹¹ A strain attacking apples has developed and reached the degree of separation so that each form can perhaps exist independently upon its respective host. It is reasonable to believe that man, by creating genetically different strains of plants, must, in time, deal with the attacks of increased numbers of physiological strains of some of their insect feeders. This appears to be explained by adapted strains of the insects being able to survive while unadapted ones perish.¹²

Codling moths sent from Colorado to Virginia did not behave with respect to their ability to enter sprayed apples as did the codling moths of Virginia.¹³ It was concluded that in this regard there were different strains of codling moths in the two States. Some strains of wheat lightly attacked by the Hessian fly in Kansas have been severely attacked in Illinois.¹⁴ It is the soft wheats which furnish many resistant strains in Kansas, while, according to the literature, in Russia the hard wheats furnish more of these strains. The semi-hard variety, Kawvale, is more heavily attacked by Hessian fly in Indiana than in Kansas.

BENEFICIAL INSECTS

Some insects accomplish useful services to mankind and are, therefore, introduced, propagated, and encouraged by man. Here follows a host of parasite introductions of the European corn borer, Japanese beetle, gypsy moth, etc. More than 50 parasites, including both native and introduced, now attack the oriental fruit moth and they offer man the chief hope of control. The introductions to control citrus pests have achieved notable results. *Trichogramma* adults have been propagated and released for the control of the codling moth, sugarcane moth borer, European corn borer, oriental fruit moth, and the greenhouse leaf tier. The introduction of the fig insect in 1901¹⁵ made possible the fig industry of California. While the caprification of figs is an essential part of that industry, it has been discovered to be complicated by the dissemination of the stem rot of these fruits. It has, however, been found possible to produce these insects in the laboratory, uncontaminated by the spores of this disease.

¹¹ Lathrop, F. H., and C. B. Nickels. The biology and control of the blueberry maggot. * * * U. S. Dep. Agr. Tech. Bull. 275, 76 pp., 1932.

¹² Thorpe, W. H. Biological races in insects and allied groups. *Biol. Rev.*, vol. 5, pp. 177-212, 1930.

¹³ Hough, Walter S. Studies of the relative resistance to arsenical poisoning of different strains of codling moth larvae. *Journ. Agr. Res.*, vol. 38, pp. 245-256, 1929.

¹⁴ Painter, R. H., et al. Resistance of varieties of winter wheat to Hessian fly. *Kansas Agr. Exp. Sta. Tech. Bull.* 27, 58 pp., 1931.

¹⁵ Condit, I. J. Caprifigs and caprification. *California Agr. Exp. Sta. Bull.* 319, pp. 341-375, 1920.

The honeybee is not a native North American insect, but was introduced by the early, thrifty colonists to function as one of the earliest factories on the continent. It is estimated that there were 4,620,650 colonies of bees in the United States in 1931 and that these colonies produced about 160,000,000 pounds of honey.¹⁶ This is an industry of no mean proportions. The honeybee has remained unchanged by centuries of domesticity, but its effect on civilization is measurable. In addition to the production of honey and wax, these creatures are receiving increased recognition as pollenizers of orchards. The late increase in the acreage of sweetclover has provided them with an additional excellent source of nectar.

LIMITATIONS PROVIDED BY CIVILIZATION

Insects do not have complete freedom in their spread. Man has set up various mechanical and artificial barriers which are more or less effective to their invasions. One thinks at once of the many quarantines enacted and promulgated to keep out undesirable foreign pests and to prevent or check the spread of those already introduced. Examples are too familiar to repeat.

The range and abundance of the Texas fever tick is being reduced markedly in the southern States. Large areas are now tick-free, owing to the persistent prosecution of a systematic program of tick eradication.

Man is the insect's worst enemy. He destroys them by barrages of poison gas, with poisoned food, and with merciless mechanical devices which trap them, crush them, or keep them out of the most attractive places. He burns them, scalds them, freezes them, starves them, or drowns them. Furthermore, he gives aid and comfort to their other enemies, such as their parasites, predators, and diseases. But where in the animal kingdom is such tenacity and persistence displayed as in insects? It is truly the battle of the centuries.

Finally, the competition offered by insects to civilized man has forced him to be a better farmer and citizen. This point should be mentioned in a low tone of voice because inborn prejudices regarding the joy of work make this a difficult point to evaluate. Nevertheless, plowing under the wheat stubble promptly after harvest to destroy the Hessian fly puparia has resulted in better seed-bed preparation for the next crop, while the fly-free planting dates in many communities are very near to or coincide exactly with the planting date for maximum yields. The mosaic disease carried by the corn leaf or sugarcane aphid (*Aphis maidis*) so seriously damages native varieties of sugarcane in the West Indies that mosaic resistant varieties

¹⁶ Olsen, Nils A. Estimated colonies and yield of honey by states, 1928, 1929, 1930, and 1931. U. S. Dep. Agr. Bur. Agr. Econ. Mimeogr. leaflet, Nov. 15, 1932.

of P. O. J. cane have been introduced, resulting in great increases in yields.

Plowing under crop residues is an effective check for many insects, such as garden insects, European corn borer, wheat stem maggot, Hessian fly, celery leaf tier, and many others. This practice restores humus to the soil and provides for better aeration. It is good **agronomic** practice.

Crop rotations tend to build up the soil or at least prevent its too rapid depletion and generally thwart insect pests. A large part of the increased yields obtained from a rotation where grains follow legumes and legumes follow grains is due to the reduction in insect damage.

Creosoting railroad ties and telephone poles to protect them against termites has protected them also from saprophytic fungi.

CONCLUSION

The progress of civilization can be interpreted in the changing status and range of many insects. This change is noted chiefly in those of economic importance but, by analogy, one may infer that many rare and unusual forms have been equally affected. However, because of their scarcity or lack of importance with reference to modern agriculture, this change is either unknown or less understood. Every specialist finds the study of species distribution very fascinating. One can never be certain whether unusual distributions or long gaps between localities in which the species occur may not be due to transportation agencies of man. The tendency toward specialized agriculture is favorable to the unbalancing of species of insects related directly or indirectly to the different hosts. This has necessitated a fiercer warfare to produce a satisfactory crop. Insects may not have learned nor consciously changed to fit the ever-changing conditions of civilization, but through survival of successful strains have just as fully met each move successfully. A stabilized environment for these creatures is as far away as the end of evolutionary development itself.

ARCTIC BUTTERFLIES

By AUSTIN H. CLARK

Curator, Division of Echinoderms, United States National Museum

[With 7 plates]

THE FAR NORTH AS A HOME FOR BUTTERFLIES

No temperatures that are found in nature are too low for butterflies—that is, for certain kinds of butterflies. We look on butterflies as harbingers of spring and as nature's dainty ornaments of our fields and gardens in the sultry days of summer. Yet some of them in their early stages can withstand the severest cold of an arctic winter, or the still severer cold at Verkhoyansk in northeastern Siberia, where the mean temperature in January is 60° below zero, and on some days it gets much colder.

Covered with ice and snow and all but inaccessible is the grim Arctic waste of Grinnell Land, just across the narrow Kennedy Channel from northwestern Greenland. Here at Lady Franklin Bay the average winter temperature is 36° below with a minimum of 73° in March, and the average summer temperature is only 34° above. Almost identical temperatures are found at Floeberg Beach, on the northern coast of Grant Land (lat. $82^{\circ}27' N.$), facing the Polar Sea with its paleocrystic ice—permanent ice of unknown age.

Desolate and forbidding as this ice-bound region is, it is far from being as barren as it looks, for plants are to be found wherever there is soil enough and sufficient warmth from the rays of the Arctic summer sun to nourish them and to permit their growth. Indeed, in this region of perpetual ice and snow where the winter temperatures are mostly below the freezing point of mercury there is a surprising wealth of plants, many of them with conspicuous and very pretty flowers. No less than 75 different kinds of vascular plants have been collected there.

This sounds almost incredible. Still more incredible seems the fact that from this grim region of eternal ice the British ships *Discovery* and *Alert* brought home no less than 35 gaily colored butterflies belonging to five different species, and two kinds of brightly colored bumblebees.

Col. Henry Wemyss Feilden, who was attached to the *Alert* as naturalist, said that during the short period when there is practically no night, butterflies are continually on the wing, if the sun's face is not obscured by clouds or passing snow showers. He also said that about 1 month in every year is the longest period in which it is possible for these insects to appear as winged adults, and that about 6 weeks is the limit of time allowed plant-feeding caterpillars, the land during all the rest of the year being under snow and ice. The caterpillars living in this region may be frozen until they become as hard as ice and as brittle as rotten twigs; yet when it warms up and they thaw out they come again to life, and begin to feed in the most unconcerned manner.

In northwestern Greenland, according to Prof. Emil Vanhöffen, beetles, butterflies, moths, wasps, flies, and a few other kinds of insects inhabit the whole rocky coastal strip that borders the inland ice, and some kinds have even been found on the nunataks—rocky islands entirely surrounded by ice. Wedged in between two ice streams of great size, with a third of its coast line on the sea, the Karajak nunatak has a rich insect fauna. On this large island between the sea and the inland ice the insects are better protected than they are on the smaller nunataks that are entirely surrounded by the ice.

Here both plant feeding and predaceous insects are in evidence, though only a few kinds are abundant. The butterflies and moths are more numerous both in individuals and in kinds than the wasps parasitic on them—their caterpillars know very well how to conceal themselves.

Far to the east of Greenland, curving in an irregular crescent about the western border of the Kara Sea south of Franz Josef Land, lies Novaya Zemlya, a long, narrow island divided near the middle by a narrow winding channel called the Matotchkin Shar. It is separated from the Siberian mainland only by the Kara Strait and Vaygach Island.

The climate of Novaya Zemlya is colder than that of Spitzbergen, though it is milder than that of the northeastern portion of Siberia. In the middle portion of the western coast the average temperature in the winter months is -4° . The average summer temperature at the Matotchkin Shar is 36.5° —lower than it is at Boothia Felix or on Melville Island north of North America—and toward the south the temperature decreases. On the eastern coast the summer temperature is lower than it is on the western coast. But thanks to the influence of a current that bathes especially the northwest coast—which may be considered as the extreme northeastern limit of the Gulf Stream drift—the shores of Novaya Zemlya are less ice-bound

than perhaps might be expected. Indeed, there are years in which the island may be circumnavigated without difficulty.

On Novaya Zemlya plant life is restricted to usually small patches, and it possesses but a scanty flora. In all there are about 160 different kinds of flowering plants, which show affinities rather with Arctic Asia than with Arctic Europe. The desolate land shows hardly a trace of animal life. Even insects are few both in kinds and numbers. But inhospitable as this island is to land-living creatures, it is the home of three different kinds of butterflies.

In rigorous regions such as these, butterflies are found, ranging northward to scarcely more than 500 miles from the Pole itself. Much farther south than this are regions seemingly more attractive and hospitable where no butterflies exist.

UNCONGENIAL REGIONS FARTHER SOUTH

Four hundred miles north-northwest of the North Cape, Europe's most northern point, somewhat farther south than Grinnell Land, lies the archipelago of Spitzbergen. A group of rocky, barren, and ice-bound islands lost in the Arctic Ocean—such is the Spitzbergen archipelago. High mountains and ice-covered plateaus make up the greater portion of its surface. Thanks to the influence of the northeasterly drift from the Gulf Stream, its climate is less severe than that in the corresponding latitudes of Greenland and the islands farther west. At Mussel Bay the average temperature for January is 14.1° and for July 39.3° . Even in the coldest winter months a thaw may set in for a few days; but on the other hand snow sometimes falls in July and August. Spring comes in June, and by the end of that month the temperature has ceased to fall below the freezing point at night.

Spitzbergen supports nearly 100 different kinds of plants, of which more than 80 are found also in Greenland, and about 70 live also in Scandinavia. Forty-three of them are very widely spread in Alpine regions, and have been found even as far away as the Himalayas. The vegetation of the northern portion recalls that of Melville Island, west of Baffin Land, while that of the south has much in common with that of Lapland and the European Alpine regions. With a milder temperature than that of Grinnell Land, and more different kinds of plants, one might expect Spitzbergen to be a more favorable habitat for butterflies. But no butterflies live there. The only representatives of the Lepidoptera are three different kinds of moths.

East of Spitzbergen and slightly farther to the northward lies the ice-bound archipelago of Franz Josef Land. Here there are

neither butterflies nor moths. Half way between Spitzbergen and the North Cape lies Bear Island. Bear Island is almost entirely ice-bound, and is colder than Spitzbergen. Here also there are neither butterflies nor moths.

Far to the southward of Novaya Zemlya's latitude—indeed south of the Arctic Circle which it only just reaches in its northern portion—is the large and interesting island known as Iceland. The climate of Iceland is not nearly so severe as might be expected from its latitude. In the south it is very wet, the rainfall is considerable, and snow storms and gales are frequent in the winter. The winter temperature is about 29° , and the summer temperature is about 53° . But the temperature varies much from year to year, the average temperature of the same month having been known to differ by as much as 27° in different years.

In the north of Iceland (at Akureyi) the climate is dry and regular. The summer temperature is about 45° , and the winter about 20° .

There are many different kinds of plants in Iceland but no trees, except for a few dwarf birches and some willow and juniper bushes.

In Iceland there are about 35 different kinds of moths, but there are no native butterflies. Four kinds of butterflies have been captured there, but all of them are stragglers from beyond the sea. These four visitors are the common cabbage butterfly (*Pieris rapae*), the red admiral (*Vanessa atalanta*), the painted lady (*V. cardui*), and the American painted lady (*V. virginiensis*). The painted lady is the most frequent visitor, and in some years rather numerous individuals cross the sea and reach the island. For instance, in July 1894 no less than five were captured. Nine other kinds of butterflies have been said to have been found in Iceland, but the records are erroneous. Iceland is too stormy and too wet for butterflies.

Much farther south than Iceland, between the parallels of 51° and 55° north latitude in the North Pacific, lie the Aleutian Islands, of which the southernmost is in approximately the same latitude as London. Here the climate is very mild. In the winter the average temperature is scarcely less than 20° , though on occasion it may go as low as 7° . Throughout the winter months the temperature on certain days may rise above the freezing point. The soil does not freeze deeper than a foot or so at most, and in some winters it does not freeze at all. The sea about these islands is open throughout the winter.

The seasons here are only two, a prolonged early spring and a short mild winter. But the sun is almost never seen. Gales and storms of

varying intensity, with fogs and mists and drizzling rains or flurries of snow occur almost continuously. A damp, raw, and chilly day with a light breeze in early spring is a fair sample of the pleasantest Aleutian summer weather. Here there are no trees, and only a few small bushes in protected situations. But wherever soil occurs there is luxuriant vegetation, and many lovely flowers, especially lupines and anemones. In spite of the lovely flowers and the numerous and interesting birds I still remember the Aleutian Islands as the most forlorn region I have ever visited. No butterflies live in this depressing chain of islands. The climate, though not cold, is too stormy and too wet for them. The Pribilof Islands, north of the Aleutians, also have no butterflies, and only seven kinds of moths.

The Aleutians and the Pribilofs have their counterparts in the Southern Hemisphere. To the eastward and somewhat north of Tierra del Fuego lies the archipelago of about 200 islands known as the Falkland Islands. Here the temperature is very equable, the average for the two midsummer months being about 47° and that for the two midwinter months about 37° . The sky is almost continuously overcast, and rain falls, mostly as a drizzle and in frequent showers, on about 250 days during the year. The rainfall is not great, being only about 20 inches, but the mean humidity for the year is 80. Owing to the absence of sunshine and of summer heat, wheat will not ripen, barley and oats can scarcely be said to do so, the common vegetables will not produce seed, and no trees will grow. The sole butterfly of the Falkland Islands is a little fritillary (*Brenthis cytheris falklandica* (pl. 3, figs. 21, 22)) that has recently been described.

Far to the eastward of the Falkland Islands and slightly farther north there lies, southeast of Africa, the large island called Kerguelen. Here the lowest temperature in winter is seldom less than 32° , and the summer temperature occasionally approaches 70° . But Kerguelen lies within the belt of rain at all seasons of the year and is reached by no drying winds. It has no trees, but on the lower mountain slopes there is much rank vegetation that is saturated with moisture constantly. There are no butterflies. The Lepidoptera are represented by a single kind of short-winged flightless moth, of which the caterpillars feed on the curious plant called the Kerguelen cabbage. Both butterflies and moths are absent from all the other islands in the Antarctic seas and from the Antarctic continent.

From this we see that the severest cold of the far northern regions can be withstood by certain kinds of butterflies. They will thrive in the most rigorous of climates, if only there is sufficient sunlight and sufficient food. But in wet and stormy regions, though the temperature may be relatively mild and equable, they are unable to exist.

THE BUTTERFLIES OF THE FARTHEST NORTH

Such is the background of butterfly life in the far north, where for only a few weeks out of every year activity is possible, where for at least 10 months out of every year all insect life is in abeyance—frozen into unconsciousness and inactivity.

Yet under these conditions butterflies and moths are far from being rare. Only very slightly more than 500 miles from the Pole itself (lat. $82^{\circ}45'$ N.) there was found the northernmost representative of the Lepidoptera. This is a fair-sized moth (*Dasychira rossi*) of plain and dingy coloring. The caterpillar of this moth has been observed feeding on saxifrage on rocks projecting from eternal ice.

Less than 40 miles farther to the southward, at Discovery Bay in Grinnell Land (lat. $81^{\circ}52'$ N.), Colonel Feilden captured two different kinds of butterflies. Both of these are little fritillaries (*Brenthis polaris* (pl. 2, figs. 13, 14) and *B. chariclea* (pl. 1, figs. 7, 8)), related to our common bog or meadow fritillaries, but dingier in color. The second of these (*B. chariclea* (pl. 1, figs. 7, 8)) Professor Vanhöffen found in northwestern Greenland flying commonly on moist sunny hillocks or over mossy meadows, though there were no flowers here for it to visit.

These two little fritillaries range farther north than any other butterflies—at least they are known from farther north than any others. But only 9 miles south of the northern limit of their range in Grinnell Land (in lat. $81^{\circ}45'$ N.) three additional kinds of butterflies were found by Colonel Feilden.

One of these is a very pretty butterfly nearly or quite 2 inches in expanse with the wings orange on the upper side, in bright sunlight with a lovely violet iridescence in the males (pl. 4, fig. 33), narrowly black-bordered. This attractive insect (*Colias hecla* (pl. 4, figs. 33, 34)) is related to our common clover butterflies, which, with their yellow or orange wings, are so conspicuous in our open fields in summer. As in the case of its more southern relatives, the female is sometimes white. D. Jenness, who collected this butterfly on Barter Island off the northern coast of Alaska, said that it flies with considerable speed in a comparatively straight line for some distance. With one exception, his specimens were all taken when the sun was shining and the temperature varied from 44° to 56° . The one exception was a male caught on a cloudy day when the temperature was 38° .

With this pretty orange butterfly there flies a variety of our common little copper (*Chrysophanus phlaeas feildeni* (pl. 6, figs. 49, 50)) in which the fore wings are lighter in color and more fiery than in the form we know so well—bronzy rather than coppery—and the

spots are smaller. The hind wings on the under side are a rather dark blue-gray.

The third butterfly found in this far northern spot was a delicate and pretty little blue (*Plebeius orbitulus* (pl. 6, figs. 47, 48)) seemingly so very frail as almost to make one wonder how it can exist at all, to say nothing of being able to live in such a place as this.

All five of these butterflies are found in Greenland, where there is still another, a green relative of our clover butterflies (*Colias nastes* (pl. 4, fig. 36)) somewhat smaller than the orange one. This a most disconcerting butterfly, for it is highly variable, and individuals taken in the same locality at the same time may differ widely in appearance.

It is one of the three butterflies that live on Novaya Zemlya. The other two are both bog fritillaries (*Brenthis*). One of these two (*B. chariclea* (pl. 1, figs. 7, 8)) has already been introduced to us as an inhabitant of Grinnell Land and Greenland. The other (*B. improba* (pl. 2, figs. 15, 16)) has not been found in either of these regions, though it lives north of North America in Baffin Land, up to about 70° north latitude, and in the extreme north of North America and Asia.

In Baffin Land and the Arctic Archipelago north of North America, and along the northern coast of North America itself, where the climate is scarcely less severe than it is in the regions farther north, there live no less than 22 different kinds of butterflies, the 7 already mentioned and 15 more.

Three of these are relatives of our common clover butterflies (*Colias*). One of them (*C. boothi*) lives in Baffin Land and on Southampton Island in the northern part of Hudson Bay, and westward to Boothia Felix and Coronation Gulf. Another (*C. pelidne* (pl. 4, fig. 35)) is found in southern Baffin Land and Labrador, and westward at least to the Mackenzie River. The third (*Colias meadi*) is a very pretty butterfly, bright orange with broad black borders to the wings, that lives in the region of Coronation Gulf and also on the high peaks of Colorado between 9,000 and 12,000 feet above the sea. From Labrador to Alaska, and from northern Siberia to Lapland and to Finmark there lives a relative of these (*C. palaeno* (pl. 4, fig. 37)) that does not range quite so far into the high Arctic regions. It is interesting to note that in the yellow clover butterflies of the far north the females are almost always white and only very rarely of the normal coloration, just the reverse of what we find in their relatives in more southern latitudes.

Of the bog fritillaries, so very characteristic of far northern regions, no less than four different kinds, in addition to the three already noticed, live in the extreme north of North America. One of these

(*Brenthis freija* (pl. 1, figs. 3, 4)) occurs from Baffin Land and Boothia Felix southward to Labrador and westward to Alaska, and also in the Rocky Mountains south to the high peaks of Colorado. In the Old World it lives from Finmark to eastern Siberia, across the extreme north of Europe and of Asia. Closely related to this species, and perhaps only a variety of it, is another (*B. natazhati*) that is found in the vicinity of Coronation Gulf and westward to the Alaskan border. In the region of Coronation Gulf and westward to Alaska still another kind (*B. pales* (pl. 2, figs. 17-20)) is found that lives also in northern Europe and eastward throughout Siberia. The last of the bog fritillaries found in the extreme north of North America (*B. gibsoni*) is known only from Southampton Island in the northern part of Hudson Bay. This is probably only a variety of a widely ranging species (*B. frigga* (pl. 1, figs. 1, 2)) that lives from northern Norway and Finmark, Esthonia and Lapland, eastward to eastern Siberia, and in North America from Baffin Land southward to Labrador, westward to Arctic Alaska, and thence southward in alpine regions to the high mountain peaks of Colorado.

Very different from the butterflies we have so far considered are the *Erebias* (cf. pl. 3, figs. 29, 30), a group of which the Scotch argus and the mountain ringlet of Scotland and the north of England are perhaps the most familiar species. These are dark brown butterflies of small or medium size related to our wood nymphs. Three different kinds are found in Boothia Felix or in the southern portion of the Arctic Archipelago north of North America. Of these 3 kinds, 2 are found also in Arctic Asia.

Related to these *Erebias* are some other butterflies of small or medium size known by the general or generic name of *Oeneis* (pl. 5, figs. 39-44). Like the *Erebias*, these live when in the caterpillar stage on grasses. They are found in the southern portion of the Arctic Archipelago north of North America, and in the extreme north of Europe and of Asia. Four different kinds of these are known from the region of Coronation Gulf. The last of the butterflies known to occur in the region of Coronation Gulf is the western checkered white (*Pieris occidentalis*).

The western portion of northern North America is much more favorable for plant and animal life than are the eastern or the central portions. Here the northern limit of tree growth reaches to the mouth of the Mackenzie River, whereas farther to the eastward it just reaches the southern shores of Hudson Bay and the southern end of Ungava Bay, thence running to the southern end of the Labrador Peninsula.

Together with the trees, several of the butterflies of the north temperate region extend their range far northward in the general

region of the Mackenzie River. The familiar gray comma of the northeastern States (*Polygonia progne*) here reaches the Arctic Ocean, together with a relative of our eastern orange tip (*Euchloë creusa* (pl. 6, figs. 53, 54)). Along the Mackenzie River and in the adjoining portion of Alaska a number of different kinds of butterflies pass the Arctic Circle that do not reach it farther to the east. The largest and most conspicuous of these are two handsome yellow swallowtails, our common yellow swallowtail (*Papilio glaucus*) and the swallowtail of Europe, which lives in northern North America as well as in Europe, north Africa, and northern Asia (*P. machaon*).

Similarly, in western Siberia and in Scandinavia many butterflies of the temperate regions range north of the Arctic Circle. Among these are the European swallowtail (*P. machaon*), the cabbage butterfly (*Pieris rapae*), the painted lady (*Vanessa cardui*), the small tortoise-shell (*Aglais urticae*), a hair-streak (*Callophrys rubi*), and a skipper (*Pyrgus centaureae* (pl. 6, figs. 51, 52)).

From the Arctic portion of the Yenesei region in western Siberia 22 different kinds of butterflies are known, including 9 bog-fritillaries, 4 *Erebias*, 2 *Oeneis*, a swallowtail, a skipper, a blue, a clover butterfly, a white, and the painted lady. Just south of this in the sub-Arctic portion of the same region 32 species have been found.

In Arctic Norway there are 46 different kinds of butterflies, of which no less than 26 occur under the parallel of 70° north latitude—that is, well north of the Arctic Circle.

In the Arctic regions taken as a whole there are 105 kinds of butterflies, some of which, however, are more or less casual visitors, or more properly belong to the sub-Arctic regions. The largest of the Arctic butterflies are the two swallowtails, both of which are found in northern North America, though only one of these (*Papilio machaon*) is found in Europe and in Asia. Most numerous are the nymphalid or brushfooted butterflies, of which there are 36, all but 10 of which are fritillaries. There are 27 wood-nymphs or satyrids, including 14 *Erebias* and 7 representatives of the genus *Oeneis*. Of the lycaenids there are 19, including 12 little blues, 6 coppers, and a single hair-streak. There are 15 pierids, including 5 whites, 5 clover butterflies or coliadids, and 3 relatives of our orange-tip; and there are 6 skippers.

Of the 79 kinds of strictly Arctic butterflies 21 are found in all far northern regions—in northern Europe, northern Asia, and northern North America. Of the remainder, 25 live only in Europe and in Asia; 17 live only in America; 6 are found in America and Asia, but not in Europe; 5 are found only in Arctic Europe; 3 live only in Arctic Asia; and 2 are found only in Europe and America.

THE BUTTERFLIES OF THE EXTREME SOUTH

In the Antarctic regions the conditions are quite different from the conditions that are found in the northern part of the Northern Hemisphere. Here lies the great continent of Antarctica, which is too cold to support plants and is thus wholly devoid of insect life. More or less remote from this are various Antarctic and sub-Antarctic islands, on none of which do butterflies exist.

The only continent that extends far enough southward to enter a region in any way comparable to the northern regions of the Northern Hemisphere is South America. But the climate of southern South America is wholly different from that of the northern portions of Europe, America, or Asia. Southern South America is so narrow that its climate is more like the climate of an island than it is like the climate of a continent.

Across the Magellan Strait from the southern extremity of continental South America lies the archipelago called "Tierra del Fuego." The eastern portion of this archipelago consists of the island called King Charles' South Land, an island very much larger than all the rest of the archipelago together, being considerably more than 200 miles in length from north to south. It forms a southern extension of the Patagonian pampas, which it much resembles in its physical constitution, and in its fauna and flora. The low-lying, flat, or slightly rolling plains are covered with a rich growth of tall herbage. In the south a long peninsula projects westward to the Pacific. This becomes rough and mountainous, with two peaks rising to nearly 7,000 feet—a true alpine region with numerous snow-clad summits and glaciers reaching to the sea.

The western and southern portions of the archipelago are essentially mountain regions, resembling the western extension of King Charles' South Land. They are extremely rough and rugged, with a much moister climate than the larger eastern island, and are densely forested, the forests consisting chiefly of an evergreen beech, and the glossy-leaved evergreen winter-bark. Above the forests, which rise to between 1,000 and 1,200 feet, there is a zone of peaty soil with stunted alpine plants that reaches as far as the snow line—that is, as high as from 3,000 to 3,500 feet. In this rough and forbidding land the winters are mild, with an average temperature of 32° for July, and the summers are cool, with an average of 50° for January, the warmest month. The mean temperature for the year is 42°. But throughout the year fogs, mists, rains, snows, and high winds prevail, and there are frequent and sudden changes from fair to foul weather.

Tierra del Fuego is the same distance south of the Equator that the Aleutian Islands are to the north of it, and the temperatures

and climatic conditions in the two island groups are very much the same. But the Aleutians have practically no sunlight, trees will not live there, and no butterflies are found in their grassy lowlands or on their boggy and mossy mountain sides.

But forbidding as it seems, the Magellanic region possesses not less than 11, and possibly 12 or 13 different kinds of butterflies, most of which are singularly similar to others in the Arctic regions. Finest of all the Magellanic butterflies is a beautiful orange clover butterfly (*Colias imperialis*) known from Port Famine. Another orange clover butterfly (*C. lesbia* (pl. 4, figs. 31, 32)), with the upper surface orange enlivened by a lovely violet iridescence and with much narrower dark margins to the wings, is also known from Tierra del Fuego. This second one ranges far to the northward, as far as southern Brazil, and also lives in the high mountains of Peru at an altitude of 12,000 feet above the sea.

Two little fritillaries, much resembling the bog fritillaries so characteristic of the Arctic regions, live in Tierra del Fuego. One of these (*Brenthis lathonioides* (= *darwinii*)) is only known from King Charles' South Land and Punta Arenas, but the other (*B. cytheris* (pl. 3, figs. 23-26)) is much more widely spread, and is found in various forms as far north as northern Chile up to altitudes of 6,000 feet; it is also represented by a local form in the Falkland Islands (pl. 3, figs. 21, 22). This last is remarkable for the great difference in the under side of the hind wings in the two sexes (compare figs. 24 and 26, pl. 3). A pretty and delicate little blue recalls the blues of Arctic and sub-Arctic regions.

The arctic and subarctic ringlets (*Erebia* (pl. 3, figs. 29, 30)) are represented in the Magellanic region by four different butterflies. One of these (*Erebia patagonica*) is surprisingly like some of the ringlets from the northern hemisphere, but the broad red-brown bands on the upper surface of the wings include no eye spots. This butterfly is not known elsewhere. Another (*Cosmosatyrus leptoneurodes*), which ranges northward in the mountains of Chile, recalls the *Callerebias* of Asia. A similar but smaller one ranges northward in the mountains to Bolivia (*C. chiliensis* (pl. 3, figs. 27, 28)) The last is much like these others, and also extends northward into Chile.

All of these butterflies, superficially at least, are so closely similar to more familiar Arctic forms that at a casual glance no one would think of them as South American. But there are four others in Tierra del Fuego (*Tatochila theodice*, *T. argyrodice*, *T. microdice*, and *T. demodice* (cf. pl. 5, figs 45, 46)) belonging to a type confined wholly to South America. In appearance these are not so very different from our northern whites, in their markings resembling

more or less our common checkered white. One of these is known only from a single female from the southern coast of Tierra del Fuego, two range northward to Peru, and one is found as far away as Ecuador and Colombia.

Only four of the butterflies of Tierra del Fuego are confined to the Magellanic region. All the others range far northward, some living high in the Andes far within the tropics, and one even passing the Equator and entering for some distance the Northern Hemisphere.

Most of the butterflies of the Magellanic region range northward for a varying distance in the Andes, rising to higher and higher altitudes in the mountains until within the tropics they are found as high Alpine species. But one of them (*Colias lesbia*) lives as a lowland species as far to the northward as Brazil. Where do the Arctic species live beyond the Arctic regions?

MORE ABOUT ARCTIC BUTTERFLIES

One of the two bog fritillaries known from farthest north (*Brenthis chariclea*) has an extensive range, and is found over a wide extent of Arctic and Alpine territory. It lives from Grinnell Land and northern Greenland southward to Labrador, westward to northern Alaska, including Wollaston and Victoria Lands, and southward along the lofty peaks of the Rocky Mountains to the Yellowstone Park. In the Old World it is found from northern Norway and Finmark eastward to Novaya Zemlya—that is, if *B. improba* is considered as a form of it. In the Old World it is local and not very common, but in America it is more generally distributed and more abundant. It is rather plentiful about the lofty summits of our western mountains.

Most interesting in connection with this butterfly is the existence of a flourishing colony far south of the southern limit of its range in Labrador in the White Mountains of New Hampshire. Here it lives in the subalpine zone of Mount Washington and the nearby peaks, and on the summits of the surrounding mountains. This is the only place where I have seen it.

Mr. Scudder wrote that it is most common about the steep heads of the great ravines that have eaten their way into the heart of Mount Washington, and in the alpine gardens. But here it is never very abundant. It flies with no great rapidity close to the ground among the scanty foliage growing in the rocky crevices of the steep mountain sides. It is fond of sunning itself on the ground with fully, or almost fully, expanded wings, and whether on the ground or on a flower it moves about with similarly expanded wings. But when entirely at rest the wings are closed.

The individuals living in the White Mountains differ somewhat from their relatives living farther north and form a well-defined local race (*montinus* (pl. 1, figs. 5, 6)).

The other far northern fritillary (*B. polaris*) lives also in Greenland and southward to Labrador (pl. 2, figs. 13, 14), thence westward along the extreme northern portion of North America to Alaska. It is found in Victoria Land and in Wollaston Land, and undoubtedly elsewhere in the great Arctic archipelago north of Canada. In the Old World it lives in the mountains of northern Norway and in Finnmark, and ranges eastward in the north of Asia to north-eastern Siberia. But it does not occur in Novaya Zemlya.

The bog fritillaries are especially characteristic of Arctic and sub-Arctic regions, and of alpine districts, though they are not confined to them. There are about 30 different kinds in the northern portion of the Northern Hemisphere. Many of these are very variable, locally or individually or both, so that many names have been bestowed upon them. Collectively they range over a vast extent of territory. They are found southward to the mountains of North Carolina and of Arizona, the islands in the Mediterranean, Asia Minor, Turkestan, the Himalayas in northwestern India, Tibet, western China, Mongolia, Korea, and Kamchatka. But strange to say, they are absent from Japan. They inhabit all sorts of regions from sea level as far south as southern Maryland up to a height of more than 15,000 feet in the Himalayas. Far removed from all their relatives are five little fritillaries corresponding to them that live in southern South America.

Very different in their habits are the various kinds of these little butterflies. Those of the far north and of high mountain tops probably require 2 years in which to complete their growth. One of the European ones is said to fly only in alternate years, at least in certain places. Most of them have a single brood a year, flying in spring or summer. A few in Asia, North America, and Europe have two broods a year. In North America some have three broods a year in the southern portion of their range, flying in spring, in summer, and in autumn; farther north, these have two broods, and still farther, only one.

Our commonest bog fritillary in the east and north is prettily spotted with bright silver on the under side (*B. myrina*). It is not a very conspicuous insect, and unless you are on the watch for it it is likely to escape your notice. Its flight is direct, and for such a little butterfly it is rather fast. It alternately flaps and glides, keeping from 2 to 6, usually about 4 inches, above the ground or grass tops. The larger individuals found in the southern portion of its

range fly at the rate of 5 or 6 miles an hour, but the smaller individuals living farther north fly at the rate of 4 or 5 miles an hour.

This butterfly is very unsuspicious, and if feeding on a flower invariably may be captured with the greatest ease. If frightened when in flight, as by the close passage of the net, it usually closes its wings over its back and drops into the grass where it conceals itself, often quite effectively. More rarely it makes off with increased speed in a zigzag flight, but without rising above the usual height. This last peculiarity probably is due to its fear of dragonflies which in great numbers infest the places where it lives. Their plane of flight is higher than that of the bog fritillaries, and although they quickly seize any unlucky butterfly that rises to their level, they will not pounce on anything below them.

This butterfly is unusually adaptable to changes in conditions. In the vicinity of Boston it commonly first appears in the last week in May, and early in June it has become abundant. A second brood is on the wing in the last week in July, and a third makes its appearance in September. In the vicinity of Washington it is not found until about the first of July, and disappears before the end of the month. Here there is only a single brood instead of three broods as farther north. Why should a butterfly appear only in midsummer in the South, but fly from spring to autumn in the North?

Together with this little butterfly there lives another (*B. bellona*) having almost the same range and commonly found with it, but easily distinguished from it by the absence of silver spots on the under side. This closely resembles the other in its habits, but is not quite so active, though its flight is similarly rapid. The one with silver spots (*B. myrina*) is characteristic especially of open grassy bogs surrounded by rough and more or less scrubby pasture land, or of grassy river bottoms, but the one without the silver spots (*B. bellona*) prefers more uniformly wet localities, particularly the boggy and grassy banks of small streams in hilly or mountainous country, or small wet hillside pastures.

One of the bog fritillaries (*B. astarte*) is described as being always found singly on the highest mountain peaks, not below 8,600 feet, far above the timber line. This one is exceedingly shy and difficult to catch. Its flight, especially the flight of the males, is very swift. It rushes and races about over the desolate rocky slopes with the wings constantly in motion, alighting but rarely, and then only for a moment. It is frightened by the least disturbance, and even the most cautious approach of the collector seems sufficient to drive it into precipitate flight. F. H. Dod says of this species that the males play around the extreme summits of the mountains at 8,000 feet or higher. They are very difficult to net, as their flight is exceptionally

swift. The females are met with, though very rarely, much lower down, almost or quite at timber line (about 7,000 feet).

Another kind (*B. alberta*), according to Edwards, flies on the steep upper slopes of the mountains, the females generally higher up than the males. The males spend most of their time racing restlessly up and down the slopes, flying so close to the ground that they appear to glide over the surface. Dr. Arthur Gibson says that this is less of a peak lover than the preceding, much more local and less common, but not nearly so difficult to capture.

In one (*B. pales*) the small individuals that live in high alpine regions rush along close to the ground with a direct and very fast flight, with the wings moving rapidly and continuously. They are fond of basking in the sun on warm stones with the wings spread widely. But the larger lowland individuals differ in their habits from the smaller alpine ones.

In most of these little butterflies the females are less active than the males, though the flight of the two sexes is very much the same. In many the females are noticeably less adept on the wing than males, and in a few (as in *B. amathusia*) the males have a rather rapid flight, the females a considerably slower and more labored flight.

Bogs, moorlands, damp meadows, wet woods, and mountain sides, form the usual home of these little fritillaries; but some fly about dry hillsides as well as in boggy places, one (*B. epithore*) lives in the waterless mountains of Utah and Arizona as well as among more congenial surroundings, and one (*B. hegemone*) flies in the Kuruktag—dry mountains—in the Gobi desert in East Turkestan, southeast of Kurla.

THE ARCTIC SATYRIDS

Companions of the bog fritillaries throughout a large portion of their range are those somber brownish butterflies of small or medium size known as *Erebias* (pl. 3, figs. 29, 30).

The *Erebias* as a whole range from the Arctic coast of North America, including the southern portion of the Arctic archipelago, southward to Hudson Bay, and in the west to the high mountain peaks of New Mexico. In the Old World they live from Scotland, northern England, and northern Norway eastward to northeastern Siberia and southward to southern Europe, Armenia, Kurdistan, northern Persia, Afghanistan, Kashmir, Tibet, Sikkim, and the mountains of central Japan. Far removed from any of its relatives, a single species is found in Patagonia.

There are about 75 kinds of these somber little butterflies, and many are very variable, so that about 200 forms have been described.

About 70 live in Asia and in Europe, and 10 in North America; but 6 of the 10 found in North America are simply American varieties of Asiatic species.

The Scotch argus and the mountain ringlet of Scotland and the north of England are perhaps the most familiar species of this group. But there are many different kinds in central Europe, and every visitor to the European mountains at the proper time of year must notice them—indeed they are common over most of Europe.

One of the commonest kinds is found over nearly the whole of Europe, and eastward to Amurland in eastern Asia. It lives in woods, in meadows, and along grass-grown roads. Its flight is slow, irregular, and somewhat skipping. The males are very common, but the females are much less often seen. They fly, as a rule, only toward the end of the season.

Several of the *Erebias* are woodland butterflies, some being found in damp pine woods, others in swampy woods, in shady places or in clearings in the forests, or in the woods of the subalpine region. The woodland species are generally sluggish with a slow, weak, and hesitating flight, and usually frequent rests. A few live both in woods and in open moorland.

But most of the *Erebias* live in treeless regions, a few on the Arctic or high northern tundras, but the great majority on mountains above the timber line, ascending to a height of more than 14,000 feet above the sea. They frequent the beautiful alpine meadows and more or less barren grassy slopes, where one cannot fail to notice them. In general their flight is sluggish, direct, fluttering, and rather weak, with frequent rests, and they keep down near the grass tops. Some, however, have a stronger and more or less skipping flight. They are fond of resting on stones or on the bare ground in sunny places with the wings half opened. Many of them are fond of flowers, and some are fond of perspiration.

On the barren ground of the mountain tops between the tree line and the snow, especially on rocky slopes, live many different kinds. These are not so easy to catch as are those of the alpine meadows. They have a rather rapid, hurried, and direct flight, keeping near the ground, and frequently flying off into places where it is impossible to follow them. In spite of their dark and seemingly conspicuous color they are very adept at concealing themselves. They are fond of sunning themselves on rocks with the wings half opened; but when so engaged they are rather shy. In Switzerland I have found them occasionally lying benumbed upon the snow with their wings closed.

All of these butterflies that I caught in Europe proved to be males, and this is the common experience of amateur collectors. The fe-

males are very sluggish, and when they fly their flight is low, weak, slow, and awkward. For the most part they remain more or less hidden in the grass and do not fly until after they have mated and some of their eggs have been laid. Their eggs are not attached to the food plant, which is usually grass, but are simply dropped in grassy places.

The fact that the *Erebias* are grass feeders serves to restrict their distribution as high Arctic butterflies in favor of others that are less particular.

A few of these butterflies are said to appear only in alternate years, at least in certain districts, and others in alternate years are more and less abundant. The reason for this is that these species require 2 years in which to reach maturity, and adverse conditions have reduced the numbers of one of the generations.

The species of the related genus *Oeneis* are about 32 in number. Some of them are found in the southern portion of the Arctic archipelago north of North America, and in the extreme north of Europe and of Asia. About one-half live only in North America, about six are found both in North America and in the Old World, and about a dozen occur only in Europe and in Asia—chiefly in Asia.

Taken as a whole the species of the genus *Oeneis* (pl. 5, figs. 39–44) have an enormous range. From southern Baffin Land they live westward to Victoria Island north of Coronation Gulf and to the northern portion of Alaska, and also from northeastern Siberia to the North Cape. Southward they are found as far as Nova Scotia, Bangor, and Mount Katahdin, Maine, Mount Washington, New Hampshire, Lake Superior and northern Michigan, North Dakota, Montana, and northern California, and in the western mountains southward to Arizona. In the Old World they range southward to Kamchatka, Korea, Mongolia, Tibet, southern Russia, the Tyrol, and Switzerland.

But over this vast area they are very irregularly distributed. Thus in the eastern United States one species (*O. jutta* (pl. 5, figs. 39, 41)) is found only in a few bogs near Bangor, Maine, and in another bog in northern Michigan; another (*O. katahdin* (pl. 5, figs. 40, 42)) is found only on Mount Katahdin; and a third (*O. melissa semidea* (pl. 5, figs. 43, 44)) lives only on Mount Washington in New Hampshire and in its immediate vicinity. The first (*O. jutta*) occurs in isolated and widely separated localities in Nova Scotia, Quebec, Yukon, and Alaska, and similarly in the Old World from eastern Siberia to Norway and southern Sweden. The second (*O. katahdin*) is known only from Mount Katahdin. Forms closely related to the third (*O. melissa semidea*) are found in Labrador, in the region of Coronation Gulf, in Yukon, and in Colorado. As a

result of their very local and spotty distribution, most of the different species of these little butterflies have many local forms. No less than 70 of these have been described, of which nearly 40 are from North America. A number of forms that we now recognize as species are probably nothing more than varieties of other species. But undoubtedly many more remain to be discovered, especially in Asia.

Very varied in their habits are the different kinds of these curious butterflies. Of the kind found on Mount Washington (*O. melissa semidea*) S. H. Scudder wrote that one would suppose that insects whose home is almost always swept by fierce blasts would be provided with powerful wings fitting them for strong and sustained flight. But the contrary is true. They can offer no resistance to the winds, and whenever they ascend more than their accustomed 2 or 3 feet above the ground, or pass the shelter of some projecting ledge of rocks, they are whirled headlong to immense distances until they can again hug the earth. He said that their flight is rather sluggish and heavy, and has less of the dancing movement than one is accustomed to see in the satyrids. They are easily captured, though they fly singly, never congregating, and have their devices to escape pursuit. One of these devices is that when alarmed, and indeed at most times, they fly up or down the slopes, rarely along them, rendering pursuit particularly difficult. Another is that they will rise in the air to get caught by the wind, which often takes them out of sight in a moment. One that he once followed with his eye whirled a good half mile away a thousand feet in the air, with a white cloud for a background.

But according to Mr. Scudder the neatest device of all is especially exasperating. One will settle on the ground a little distance off by a crevice in the rock piles, and as you cautiously approach you will see it edge its way afoot in its spasmodic fashion to the brink of the crevice and settle itself. Then if you come nearer it will start as if to fly away, but instead close its wings and fairly drop down the crevice, where you may see it, but not reach it, to repeat the process and get still farther down if again alarmed by the removal of the upper rocks. In this way he more than once followed one for a couple of feet downward in a pile of small jagged rocks in one of the rock rivulets.

Mr. Scudder said that this butterfly rests on the ground, or on the leeward side of rocks, as he often found it when searching on a cloudy day when it had not been on the wing. As soon as one alights it tumbles upon one side with a sudden fall, but not quite to the surface, exposing the under side of the wings with their marbled markings next to the gray rock mottled with brown and yellow

lichens, so that an ordinary passer-by would look at them without observing their presence. The surface of the wings is generally exposed so as to receive the fullest rays of the sun, or else the creature falls so as to let the wind sweep over it, its base to windward. In either case the fore wings are not fully drawn back between the hind wings. But when at rest for the night, or if the wind be sweeping fiercely, the fore wings are drawn completely back between the hind wings. These butterflies are fond of flowers, and often alight on the blossoms of the moss campion, or on some plant of the heath family, particularly blueberries. They are also fond of the flowers of the mountain sandwort.

The best collecting places for this species are the sedgy plateaus of the northeastern and southern sides of Mount Washington. They are found most abundantly from about one-quarter to three-quarters of a mile from the summit, at an elevation of about 5,600 to 6,200 feet above the sea. He never found them about the heads of any of the deep ravines where the White Mountain fritillary (*Brenthis chariclea montinus* (pl. 1, figs. 5, 6)) is most common.

Bogs and morasses form the chosen home of that relative of the White Mountain butterfly that is found near Bangor, Maine (*O. jutta* (pl. 5, figs. 39, 41)). Wherever it occurs it is to be found only in such uninviting places. And within the bogs themselves it is often very local, living only in a small section of them, only where sphagnum is abundant. This butterfly has rather a quick flight and is hard to catch. It rarely rises above the tops of the laurels and other low bushes of the bogs, seldom alights, and is fond of circling around the clumps of juniper bushes that here and there occur. When it does alight, it usually chooses tree trunks for a resting place. In the mating season the females usually rest high up in the trees, and in their search for them the males fly around and up the trunks. This insect is shy and easily startled. When it walks it moves by little jerks, with each jerk advancing less than one quarter of its length. If the wind blows upon it when it is at rest, it tucks the fore wings down between the hind wings so as to reduce the wing area as much as possible.

Much larger and more brightly colored than these two is another kind that is found about the northern end of Lake Superior (*O. macounii*). According to Mr. Scudder the movements of this butterfly are swift, and in spite of their satyrid character are not unlike those of the viceroy (*Basilarchia archippus*), which when on the wing it much resembles.

These three native species well illustrate the diversity among the species of *Oeneis* as a whole. They live in swampy meadows, on grassy mountain slopes, along the edges of woods, especially coniferous

woods, in larch woods, or on dry, rocky, and barren slopes. Some prefer to rest on the branches of trees, others on the trunks, still others on rocks or on the bare ground, and a few hide in the grass, avoiding both rocks and trees. Some are fond of flowers, though others are seldom or never found on them. Many are shy, with a rapid flight, and difficult to catch; though some, especially such as live in grassy places, fly weakly and only for short distances. The females are much less active than the males, and in some kinds fly but rarely, so that they are much less often caught. Some of them in portions of their range are found only in alternate years, but in different years in different places, and these, and others, may vary more or less widely in abundance in alternate years.

THE PIERIDS, LYCAENIDS, AND SKIPPERS

Especially characteristic of high Arctic regions are several different kinds of butterflies related to our common yellow or orange clover and alfalfa butterflies (*Colias*) that are so very common in our fields in summer.

The butterflies of this group are very numerous, comprising about 80 different species. Many of these are very variable, locally, seasonally, or individually, and the females often occur in an albinistic as well as in a normal color phase. As a result of this variation more than 300 forms are recognized.

More than half the species live in central Asia. In North America there are 15 species with 31 forms, most of them living in the northwest and in the mountains of the west, usually at high altitudes. There are eight species in South America, which are for the most part found high in the Andes from Colombia to Chile, but one lives on the southern plains, and one of the very finest of the genus is confined to Tierra del Fuego. Two are found in Africa, one throughout the continent, and the other in the northeastern section. In India south of the Himalayas one lives in the Nilghiri Hills.

These butterflies live in open country, and especially in rough and mountainous country. Nearly all of them are active and fast fliers, the males especially.

The little copper butterfly found in the far north (*Chrysophanus phlaeas feildeni* (pl. 6, figs. 49, 50)) occurs in Greenland and southward to Southampton Island and to Labrador, thence westward to Alaska. In a somewhat modified form it lives in Norway, in Sweden, and in Finland. The species (*Chrysophanus phlaeas*) of which this is simply a geographical variety lives all over North America, except in the extreme south. In the Old World it ranges from the Arctic regions southward to Madeira and the Canary Islands, the oases of the Sahara, Asia Minor, northern India, China, and Japan. In the

Himalayas it is found 12,000 feet or more above the sea; but it is much more of a lowland than a mountain butterfly. In the Old World, especially in the southern portion of its range in Asia, it is extremely variable, both geographically and seasonally. It is also very variable in southern Europe. But it is much less variable in America.

The pretty little blue of the far north (*Plebeius orbitulus* (pl. 6, figs. 47, 48)) is found in Greenland and southward to Labrador, thence westward to Alaska. Varieties, or closely related forms, range southward to the mountains of California and Colorado. In the Old World it lives from northern Norway across Siberia to Kamchatka and southward in the higher mountains to Spain, Asia Minor, Kashmir, and Tibet.

This is the commonest butterfly of the high Alps, and is even plentiful at the snow line. According to Dr. A. Seitz it is found locally in countless numbers in the region of the higher alpine pastures. It swarms everywhere over detritus and grass, always keeping close to the ground, settling with half-opened wings on flowers of all kinds. Often clouds of them assemble at small puddles in the roads, and they are even fond of drinking on the melting snow. When a cold wind from the glacier strikes them, or the sun is hidden by a cloud, they become at once lethargic and often helplessly tumble on their sides, remaining in this position until the warm rays of the sun revive them. Their flight is fast, but they are not shy. I have collected a number of them in Switzerland.

The little skipper (*Pyrgus centaureae* (pl. 6, figs. 51, 52)) that enters the Arctic regions lives in Scandinavia and Finland, and also in the Altai Mountains. In North America it is found in Labrador and Quebec, and from northern British Columbia southward to the mountains of Colorado. It also occurs from southern New York southward to the mountains of North Carolina, where it is on the wing only in April and in early May.

ARCTIC AND ALPINE BUTTERFLIES

In the far north the butterflies make no distinction between lowlands and higher country, occurring wherever they can find support. Farther to the southward most of them become upland and finally alpine types. But this is by no means true of all of them. For instance, the little copper (*Chrysophanus phlaeas*) is not an upland species in Africa or in Japan, nor is it a true upland butterfly in the southern portion of the United States.

The grizzled skipper (*Pyrgus centaureae* (pl. 6, figs. 51, 52)) becomes an alpine butterfly in our western mountains, and in Asia in the Altai Mountains; but it is a lowland butterfly from southern New

York southward to Virginia, and not a true upland butterfly even so far south as Carolina. In this interesting southern colony it flies chiefly in the latter half of April, at the latest in early May, when the temperature is about the same as it is in midsummer in its northern or alpine home. In its early stages it withstands the intense heat of the prolonged southern summer quite as well as the intense cold of the long Arctic or alpine winter.

The clover butterflies (*Colias*) and the bog fritillaries (*Brenthis*) are for the most part mountain or northern butterflies; yet both groups include southern lowland species.

A number of different kinds of butterflies are confined to high alpine regions that do not extend into the Arctic area. On the high mountain tops in central Asia at a height of from 15,000 to 18,300 feet above the sea and even higher, in regions destitute of all traces of plant life, live some curious little butterflies belonging to the genus *Baltia*. According to Dr. R. Fruhstorfer these curious little pierids play in the sun or run about with half-opened wings over the sandy soil, sometimes traversing long distances. If they are disturbed they quickly hide away among the inequalities of the ground. When they fly they always keep near the ground.

Very similar, though really only distantly related, pierids (*Andina* (pl. 4, fig. 38)) are found among the barren and desolate masses of rock on the highest summits of the Andes, at an elevation of about 19,300 feet above the sea. Garlepp, who discovered them, said he could not understand why this butterfly should choose such wastes and deserts, or how it can exist where there is absolutely no vegetation, where it must sometimes be daily covered with snow and ice, and where only the condor makes its abode. At these great altitudes tempestuous winds constantly prevail, so that the insect can fly only in the brief lulls.

Probably the most familiar and most generally known of all the alpine butterflies are the lovely white parnassians (*Parnassius* (pl. 7)) so common in the European and Asiatic mountains, and in the higher altitudes in our western States. These are the largest of the alpine butterflies, and in Europe, Asia, and western North America they form a characteristic and most attractive element in the alpine landscape, especially of the higher mountain meadows and more or less verdant slopes, or at least green patches.

There are nearly 30 different kinds of these lovely butterflies, and most of them are highly variable, locally and individually. They are found in the mountainous regions of Europe, except the British Isles, southward to Spain, Italy and Greece, in Asia Minor, and eastward to Kamchatka and the mountains of Japan, southward to the Himalayas. In North America they range from Alaska south-

ward in the mountains to New Mexico. Here they are represented by four different species with about a dozen forms. The species found in North America scarcely differ from others found in Asia.

In the parnassians the flight of the males in the hot sunshine is easy and graceful. They progress by flapping and irregularly sailing with many turns and twists, stopping from time to time to feed on flowers with the wings expanded. They fly rather near the ground and rather hurriedly, and if it suddenly turns cold or rainy they take refuge in the herbage where their large size and white color makes them conspicuous. The females are less active than the males, and have a more clumsy and more fluttering flight, though when it is cold the males fly in the same awkward and hesitating manner as the females.

Some parnassians have a curious habit of drifting irregularly up a valley in the morning, and down again in the afternoon. In the high altitudes at which they live exertion becomes difficult. One cannot chase a butterfly without very soon becoming distressed. But this curious habit makes their capture easy. On the mountain side above the town of Chamounix in France I found a shallow valley in which the finest of the European species (*Parnassius apollo*) was unusually common. From a seat on a stone high up in the middle of this valley I could see the butterflies zigzagging irregularly upward, flying back and forth across the valley as they came. As they approached I could judge about where they would pass in their diagonal flight and, by walking a few paces up or down, could easily intercept and capture them. If they are frightened they may make off at a very creditable pace, and then pursuit is all but hopeless. When depositing their eggs the females fly low with a curious slow, hesitating flight, and frequently alight upon the food plant. As a rule they are not shy, and are easily followed up and caught.

Although nearly all of the parnassians are mountain butterflies, a few are found on the northern plains. They can withstand the most rigorous conditions on the high mountain peaks of central Asia and of Colorado, but none of them lives as far north as the Arctic regions. The farthest north that any has been found is Viliusk (lat. 63° 35' N.) in the valley of the Lena River. Here *Parnassius tenedius* has been taken. This is not very far away from Verkhoiansk, the "cold pole" of the world, in the valley of the adjacent Jana River. One of the common European species (*P. mnemosyne*) ranges almost as far north.

The butterflies of the far north and those of alpine regions are very variable from place to place and run into many puzzling forms, largely as a result of living in relatively small colonies in more or less widely separated localities. In the mountains the individuals of

a single species sometimes differ not only in adjacent valleys, but sometimes also in different portions of the same valley, or on different sides of the same peak.

Probably all of the butterflies of the far north, and many of the alpine types as well, require 2 years, some possibly longer, in which to complete their transformations. Yet a few of the parnassians living high in the Himalayas in northern India have two broods a year.

As a rule, arctic and alpine butterflies are smaller than their relatives farther south or in the valleys, and are also dingier or darker in color, at least on the under side. Their bodies and heads are very hairy.

THE BUTTERFLIES OF SPRING

Spring begins in earnest in the vicinity of Washington, D. C., about the middle of March. The conspicuous white flowers of the bloodroot appear in the woods above the carpet of fallen leaves. The leafy rosettes of the dandelions, the thistles, and the milfoil, bright green and fresh, are of good size, and the clovers, grasses, daisies, and other low-growing plants have put forth many bright green leaves. The trees as yet are leafless, but the elms, willows, alders, spice-bush, and some others are in flower. The cardinals, song-sparrows, robins, white-throated sparrows, mourning doves, and all of the smaller frogs are in full song, and the flickers and the phoebes are heard on all sides. Turtles are appearing on the logs and mud banks, reveling in the stimulation of the bright sunlight after the darkness of their long hibernation. At this time or somewhat later in April, no less than 34 different kinds of butterflies are to be found upon the wing. These 34 species are divisible into four groups.

The largest group includes 16 species all confined to North America, but ranging widely throughout the continent. All of them live far to the northward, though only one, the yellow swallowtail (*Papilio glaucus*) passes the Arctic Circle. All of these have at least two broods a year.

The next largest group includes eight southern species, about half of which range southward into the Tropics. The most interesting in this group are the blue swallowtail (*Papilio philenor*), the zebra swallowtail (*P. marcellus*), and the orange-tip (*Anthocaris genutia*). In this group falls the most brilliantly colored of all the local butterflies, the lovely azure hair-streak (*Strymon m-album*). All but the orange-tip have at least two broods a year. The last has only a single brood in the vicinity of Washington, flying from March to early May; but in the cooler mountain regions farther south there are two

broods, one in early spring and one in early summer. Dr. W. J. Holland says that in the mountains of western North Carolina there is also an autumnal brood.

The third group includes five butterflies of boreal, but not Arctic, range. These have only a single brood a year.

The last group includes five species that range widely throughout the northern hemisphere. These are the mourning cloak (*Aglais antiopa*), the common blue (*Lycaenopsis argiolus*), the cabbage butterfly (*Pieris rapae*), the small copper (*Chrysophanus phlaeas*), and the grizzled skipper (*Pyrgus centaureae* (pl. 6, figs. 51, 52)). All, with the exception of the last, have at least two broods a year. All of them range far to the northward into the Arctic, or at least high sub-Arctic regions. The common blue (*Lycaenopsis argiolus*), like the little copper (*Chrysophanus phlaeas*), has an enormous range in both the New and the Old Worlds, and occurs in a bewildering array of local and seasonal forms, with many individual variants.

The most interesting thing about the common blue in the present connection is that the early spring individuals captured in the vicinity of Washington resemble others caught in the far north near the Arctic Circle, where the butterfly has only a single brood. Later spring individuals resemble individuals of the summer brood in the most northern localities in which a summer brood occurs. But the mid- and late-summer forms are quite different from any of the forms found in the North.

In the case of the little copper, the individuals that appear earliest in the spring have the fore wings much lighter in color and with smaller spots than those seen later, and the under side of the hind wings is darker. In other words, they show an approach to the far northern form *feildenii* (pl. 6, figs. 49, 50), though the correspondence between the early spring and far northern individuals of the small copper is by no means so close as it is in the case of the common blue, where it amounts practically to identity.

The same phenomenon is illustrated by the yellow swallowtail (*Papilio glaucus*). In this butterfly the earliest spring individuals are of the same size and color, with the same long hair on the head and body, as their representatives from farthest north. Indeed, some of the specimens from the vicinity of Washington taken in early spring are quite indistinguishable from others from north-central Alaska. No females have ever been found in early spring near Washington, and it is possible that here this form exists in the male sex only.

It is perhaps to be expected that in butterflies ranging northward to Arctic or sub-Arctic regions the first individuals to appear in spring in the southern portion of the habitat should resemble those

flying in summer farther north. But corresponding differences are found between the early spring and later individuals in butterflies that are wholly southern in their distribution.

This is well illustrated by the zebra swallowtail (*Papilio marcellus*), of which the individuals flying in early spring are very small and very hairy, corresponding to the earliest individuals of the yellow swallowtail (*P. glaucus*). It is also seen in the blue swallowtail (*P. philenor*) in which the form found in early spring in the vicinity of Washington is very small and very hairy, with the light spots on the upper surface of the wings large and conspicuous.

These early spring individuals of the blue swallowtail approach more or less closely the individuals of the Californian form (*hirsuta*). With them there are occasionally found individuals of a tailless form (*acauda*) that are almost or quite identical with others from the hot lands of Mexico.

Speaking of butterflies of hot lands and more or less arid regions, it may be mentioned that in all of our western and southwestern swallowtails (*Papilio rutilus*, *P. daunus*, and *P. pilumnus*) there is on the under side of the fore wings just within the outer border a broad, yellow, tapering band that takes the place of the row of spots seen in the common yellow swallowtail in summer. In the far north, in the high mountains of India and of central Asia, and in the vicinity of Washington in early spring the yellow swallowtails (*Papilio machaon* and *P. glaucus*) all have this yellow band, just as do the arid country species.

Speaking of these yellow swallowtails, it is of interest to note that our American yellow swallowtail (*P. glaucus*) in the far north flies together with the Old World swallowtail (*P. machaon*) both in the region of Hudson Bay and in Alaska. In the region about Hudson Bay the Old World species occurs in a form (*hudsonianus*) that is scarcely different from the form found in northern Europe, but in Alaska the local form (*alaska*) is an offshoot from a group of similar forms living in the Himalayas and in the mountains of eastern Asia. In these two regions the local representatives of the American yellow swallowtail also show considerable differences.

ANALYSIS OF THE ARCTIC BUTTERFLY FAUNA

The outstanding and important characteristic of the Arctic archipelago, according to Prof. Robert F. Griggs, is its extreme dryness. The annual precipitation in all high Arctic countries is less than 10 inches, a deficiency in rainfall that in lower latitudes would invariably mark a desert. Middendorf long ago described the Siberian tundra as the most extreme desert, and said that it was too dry to be compared with any region familiar to Europeans.

In this connection the occurrence of the broad submarginal band on the under side of the fore wings in the Arctic yellow swallowtails as well as in all the yellow swallowtails of our more or less arid western country is of interest. Still more interesting is the occurrence of the same band in the very small yellow swallowtails of early spring in the vicinity of Washington, together with the practically tailless form (*acauda*) of the blue swallowtail (*Papilio philenor*) which is otherwise known only from Mexico and the southern portion of New Mexico. These occur, however, only if the warm weather of early spring follows immediately after very cold weather; if the passage of winter into summer is gradual they do not appear. All of the butterflies living about Washington that have both a "wet" and a "dry" form occur in early spring only in the latter. Such are the buckeye (*Junonia coenia*), the painted lady (*Vanessa cardui*), the anglewings (*Polygonia*) and the orange clover butterflies (*Colias eurytheme*). In the case of the buckeye and the painted lady the "wet" form together with the "dry" is found in the late autumn, but only the "dry" lives through the winter. Among the most characteristics of the Arctic butterflies are the clover butterflies (*Colias*), the bog fritillaries (*Brenthis*), the little blues (*Lycaenidae*), and the satyrids (*Satyridae*). In the arid regions of the Tropics we find as characteristic butterflies close relatives of the clover butterflies (especially *Catopsilia*), various little blues, and certain satyrids. Furthermore, some of the bog fritillaries live in regions that for a large portion of the year are extremely dry.

Professor Griggs has pointed out that the floral characteristics of the Arctic are chiefly negative, owing to the absence from northern lands of species occurring in southern latitudes. This is quite as true of Arctic butterflies as it is of Arctic plants.

Although all Arctic plants are more or less dwarfed and usually rise but little above the ground, they exhibit no structural peculiarities that differentiate them from allied species farther south. Among the butterflies all the Arctic species or varieties are more or less dwarfed, but they show no structural differences as compared with others from other regions. In addition to being dwarfed they are more or less suffused with black or blackish, at least on the under side, and the head and body are very hairy. These features are shared with early spring butterflies from regions much farther south, especially in eastern North America. One of the clover butterflies in the vicinity of Washington (*Colias eurytheme*) in early spring appears in a small and very pale form with only a slight trace of orange on the upper side, and dark greenish on the under side of the hind wings. In autumn, if the season be hot and dry, this small light form reappears, but without the dark suffusion on the under side.

Sir Joseph Hooker wrote that "of the plants found north of the Arctic Circle very few are absolutely or almost confined to frigid latitudes (only 50 out of 762 or so); the remainder, so far as their southern distribution is concerned, may be referred to two classes; one consisting of plants widely diffused over the plains of northern Europe, Asia, and America, of which there are upwards of 500; the other of plants more or less confined to the alps of these countries, and still more southern regions, of which there are only about 200."

Essentially the same is true among the butterflies.

Professor Griggs has written that the vegetation of the Arctic resembles most closely that of waste lands—the vegetation of recently ploughed fields, earth slides, freshly exposed gravel banks, etc. "Such common weeds as the sheep sorrel, the common horsetail, chickweed, winter cress, rib grass, Kentucky blue grass, cuckoo flower, tall buttercup, fireweed, and Rhode Island bentgrass range far north in the Arctic, some of them to the north coast of Greenland."

The general aspect of the Arctic butterfly fauna is very much the same. The butterflies of the Arctic are representatives of types that are elsewhere characteristic of rough and forbidding country, waste lands, or more or less arid regions, or at least that occur in such unfavorable situations.

EXPLANATION OF PLATES

(All of the specimens figured are in the collection of the United States National Museum)

PLATE 1

FIGURE 1. *Brenthis frigga*, Torneå, Finland (Barnes collection).

2. Same, under side.

3. *Brenthis freija*, Helsingfors, Finland (Barnes collection).

4. Same, under side.

5. *Brenthis chariclea montinus*, Mount Washington, New Hampshire (Barnes collection).

6. Same, under side.

7. *Brenthis chariclea arctica*, Greenland (Barnes collection).

8. Same, under side.

9. *Brenthis aphirape tricularis*, Atlin, northern British Columbia (Barnes collection).

10. Same, under side.

PLATE 2

FIGURE 11. *Brenthis frigga saga*, Kettle Rapids, Nelson River, on the Hudson Bay Railroad, July 8, 1914 (Barnes collection).

12. Same, under side.

13. *Brenthis polaris*, Okak, Labrador, August 16, 1923 (Barnes collection).

14. Same, under side.

- FIGURE 15. *Brenthis improba*, Bernard Harbor, Arctic coast of North America, Northwest Territory; Canadian Arctic Expedition; Fritz Johannsen, July 1916 (Barnes collection).
16. Same, under side.
17. *Brenthis pales*, Albula Pass, Upper Engadine, Switzerland (Barnes collection).
18. Same, under side.
19. *Brenthis pales alaskensis*, Alaskan Arctic coastal plain, lat. 69° N. (Barnes collection).
20. Same, under side.

PLATE 3

- FIGURE 21. *Brenthis cytheris falklandica*, Port Stanley, Falkland Islands; collected by Karl Vernon Lellman for Dr. Waldo L. Schmitt.
22. Same, under side.
23. *Brenthis cytheris*, male.
24. Same, under side.
25. *Brenthis cytheris*, female (W. Schaus collection).
26. Same, under side.
27. *Cosmosatyrus chiliensis*.
28. Same, under side.
29. *Erebia vidleri*, Lalood, British Columbia, 4,500 feet altitude, July 14, 1916 (Barnes collection).
30. Same, under side.

PLATE 4

- FIGURE 31. *Colias lesbia*, male, La Rioja, Argentina, E. Giacornelli.
32. *Colias lesbia*, female, Montevideo, Uruguay, J. Felippone.
33. *Colias hecla*, male, Greenland, M. Bartel (Barnes collection).
34. *Colias hecla*, female, Umanak, Greenland, July 21, 1914 (Barnes collection).
35. *Colias pelidne*, male, Okak, Labrador, August 16, 1923 (Barnes collection).
36. *Colias nastes*, female, Wilcox Pass, Clark, July 1930 (Barnes collection, from the Oberthür collection).
37. *Colias palaeno*, male, Gellivare, Lapland, Sweden, M. Bartel (Barnes collection).
38. *Andina huanaco*, male, Bolivia (Neumögen collection).

PLATE 5

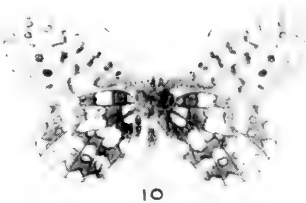
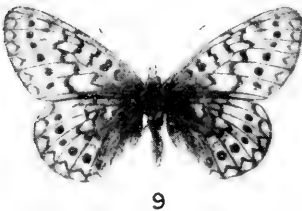
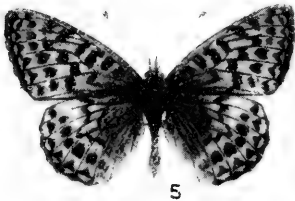
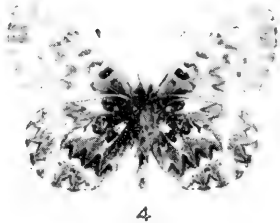
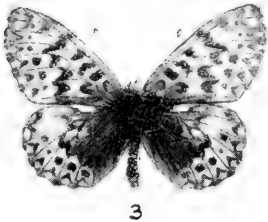
- FIGURE 39. *Oeneis jutta*, female, Passadumkeag, on the Penobscot River about 30 miles north of Bangor, Maine, July 11, 1933 (Barnes collection).
40. *Oeneis katahdin*, Mount Katahdin, Maine, H. H. Newcomb, June 29, 1901 (Barnes collection, through P. G. Bolster).
41. *Oeneis jutta*; under side of the specimen shown in figure 39.
42. *Oeneis katahdin*; under side of the specimen shown in figure 40.
43. *Oeneis melissa semidea*, Alpine Gardens, Mount Washington, N. H., 5,000 feet altitude (Barnes collection).
44. Same, under side.
45. *Tatochila xanthodice*, male, Tarqui, Ecuador, F. Campos.
46. *Tatochila xanthodice*, female, Ecuador (Neumögen collection).

PLATE 6

- FIGURE 47. *Plebeius orbitulus*, Atlin, northern British Columbia (Barnes collection). $\times 1\frac{1}{2}$.
48. Same, under side. $\times 1\frac{1}{2}$.
49. *Chrysophanus phlacas feildeni*, McCormicks Bay, Smith Sound northwestern Greenland, August 4, 1892 (Barnes collection). $\times 1\frac{1}{2}$.
50. Same, under side. $\times 1\frac{1}{2}$.
51. *Pyrgus centaureae*, Paterson, N. J., April 16 (Barnes collection). $\times 1\frac{1}{2}$.
52. Same, under side. $\times 1\frac{1}{2}$.
53. *Euchloë creusa*, Atlin, northern British Columbia (Barnes collection). Natural size.
54. Same, under side. Natural size.

PLATE 7

- FIGURE 55. *Parnassius apollo hesebolus*, male, Kuldja, Ili Province, Sungaria (Neumögen collection).
56. *Parnassius discobolus*, female, Kuldja, Ili Province, Sungaria (Neumögen collection).



ARCTIC BUTTERFLIES.

(For explanation see page 294.)



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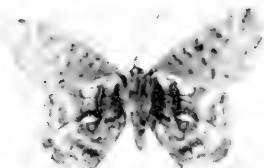
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ARCTIC BUTTERFLIES.

(For explanation, see page 294.)



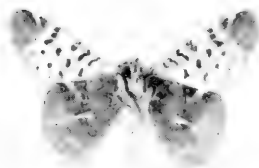
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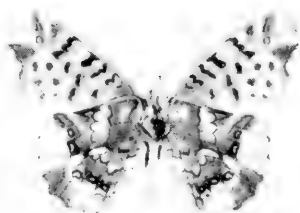
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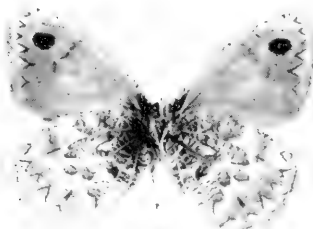
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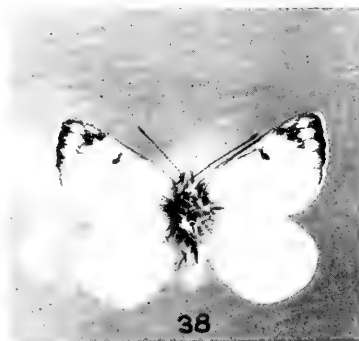
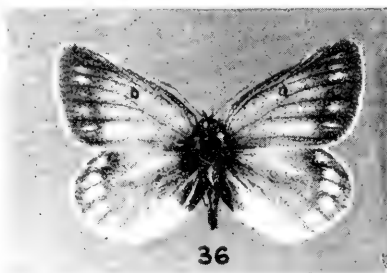
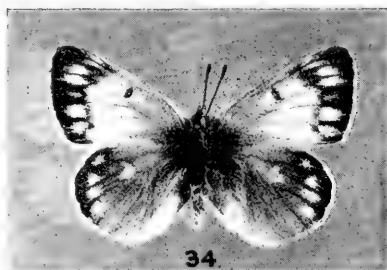
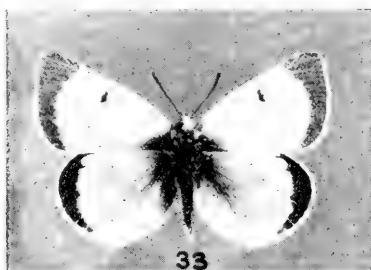
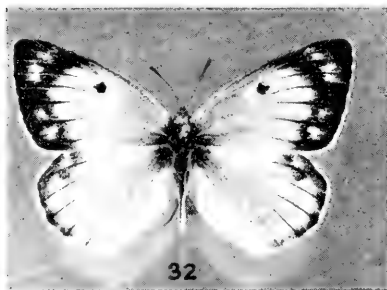
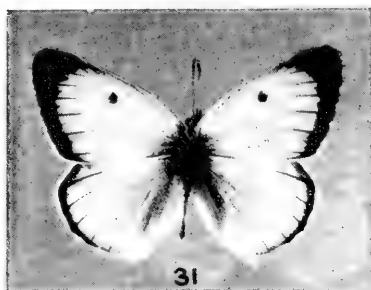


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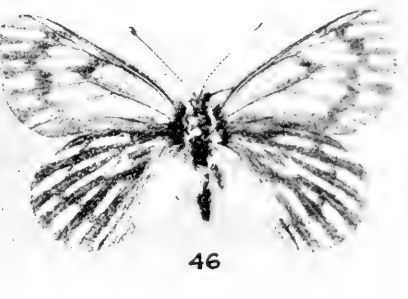
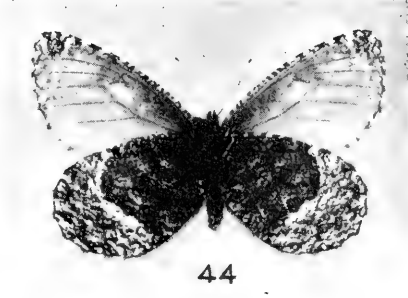
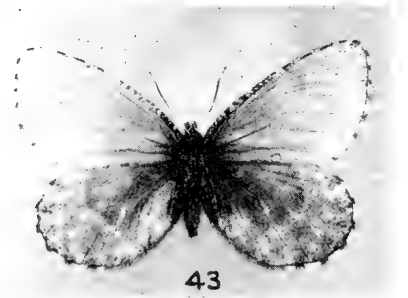
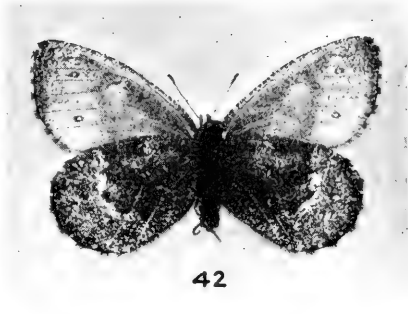
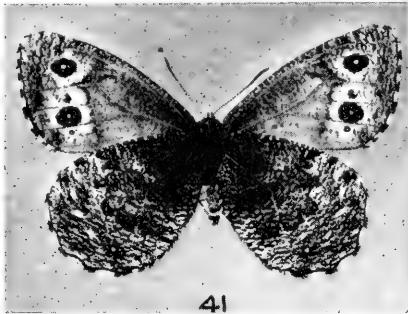
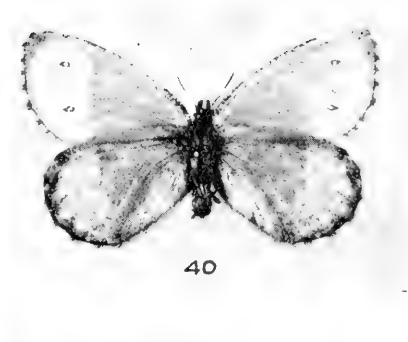
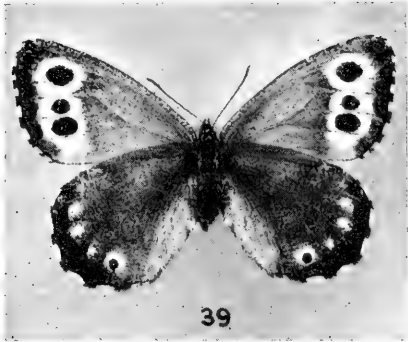


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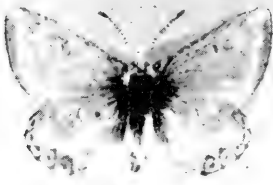
ARCTIC BUTTERFLIES.
(For explanation, see page 295.)



ARCTIC BUTTERFLIES.
(For explanation, see page 295.)



ARCTIC BUTTERFLIES.
(For explanation, see page 295.)



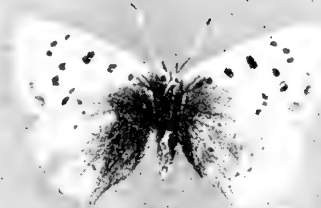
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ARCTIC BUTTERFLIES.
(For explanation, see page 296.)



ARCTIC BUTTERFLIES.
(For explanation, see page 296.)

GRASSES, WHAT THEY ARE AND WHERE THEY LIVE

By A. S. HITCHCOCK

Principal Botanist in Charge of Systematic Agrostology, United States Department of Agriculture

[With 8 plates]

The flowering plants of the world are divided among about 300 families. Of these the grass family (Gramineae or Poaceae) is the most useful to man. From the botanical standpoint grasses are plants which possess certain structural characteristics that differentiate them from other families. The grasses were recognized as a natural group long before there was a science of botany or a system of classification, just as palms, cactuses, and legumes were recognized as plant families even by primitive peoples. Our common meadow, pasture, and lawn grasses, such as timothy, redbtop, bluegrass, and Bermuda grass, are known to nearly everyone. Many people also know as grasses the numerous wild prairie grasses and such common weeds as crabgrass and quackgrass. But it is news to some that the grass family includes the grains or cereals, such as wheat, oats, rye, barley, corn (maize), and rice, as well as sugarcane, sorghum, and millet, and the woody-stemmed bamboos.

Those who are not very discerning may include among the grasses other plants with long narrow leaves, such as sedges, rushes, and even narrow-leaved lilies. The tendency to include the term grass as a part of the common name of plants, other than grasses, having narrow leaves, is shown by such names as beargrass (*Xerophyllum tenax*), a kind of lily, common in our Northwestern States; blue-eyed-grass (species of *Sisyrinchium*), small plants of the iris family; ribgrass (*Plantago lanceolata*), a narrow-leaved plantain; eelgrass (*Zostera marina*), a submerged plant of the pondweed family growing along our coasts; sawgrass (*Mariscus* or *Cladium*), a large sedge with vicious saw-edged leaves, especially abundant in the Florida everglades; and stargrass (*Hypoxis*), of the amaryllis family, with small yellow flowers.

To the farmer or stockman grass may mean almost any herbaceous plants upon which animals graze, including clovers, alfalfa, and other legumes. Indeed, the English word grass is derived from the same root as graze, grass being the principal part of grazed herbage.

STRUCTURE

The structures which the various grasses have in common and which together distinguish them from other families are the jointed stems, hollow as in wheat, or pithy with solid joints or nodes as in corn and sorghum; leaves alternate in two ranks, and consisting of two parts, the sheath and the blade, the sheath surrounding the stem like a tube, the blades diverging more or less. Any plant with such a stem and such leaves is a grass.

INFLORESCENCE

The inflorescence or flowering part of grasses is borne at the top of the stem or at the ends of the branches. The flowers are borne in the axils of bracts on minute specialized branchlets called spikelets. The flowers are inconspicuous, without calyx or corolla. They consist of a single pistil with a one-celled ovary, two styles with feathery stigmas, and usually three stamens. Each flower is borne between two small green bracts. The ripened ovary, the grain, has a small embryo and a large mass of starchy endosperm. The "germ" of a kernel of corn is the embryo; the rest of the kernel is endosperm. At the base of the spikelet are two empty bracts, the glumes. These are very large in the oat, and minute in bluegrass. The spikelet may contain a single floret (the flower with its two bracts) as in redtop and timothy; two or three as in the oat, or several to many, as in bluegrasses, fescues, and brome grasses. The florets, like the leaves on the culm, are always two-ranked.

If we examine a head of wheat we find a central flat zigzag axis with spikelets about half an inch long in an overlapping row on each side. In bearded wheats the spikelets bear long awns or bristles. Each spikelet contains several bracts (in rows), within which are the flowers as described above.

The form of the inflorescence in grasses is very diverse, and it is this which gives the characteristic aspect to the different species. Barley and rye have heads or spikes like wheat. In oats the large spikelets are borne on long pedicels in an open panicle. In redtop, bluegrass, and the fescues the spikelets are borne in rather loose panicles, whereas in timothy the panicle branches and pedicels are so short that the spikelets are closely packed in a cylindrical head or spike. In sugarcane, giant reed (*Arundo*), and pampasgrass (*Cortaderia*) there is a large number of spikelets in a great feathery

mass or plume. In crabgrasses (*Digitaria*), Bermuda grass (*Cynodon*), and goosegrass (*Eleusine*) the spikelets are borne in slender one-sided digitate (fingerlike) spikes.

Most grasses have perfect flowers (stamens and pistils in the same flower). Those with unisexual flowers (containing only stamens or only pistils) may be monoecious (the two kinds of flowers on different parts of the same plant, as in corn) or dioecious (the two kinds of flowers on different plants, as in buffalo grass (*Buchloë*) and saltgrass (*Distichlis*)).

POLLINATION

Basically, the pollination and fertilization of grasses is the same as in other kinds of flowering plants. The pollen produced by the stamens is transferred to the stigmas of the pistil, the process being called pollination. There the pollen germinates and (by means of a minute tube) grows down through the style into the ovary and finally to the germ cell of the ovule. The protoplasm of the end of the pollen tube fuses with the protoplasm of the germ cell, fertilizing it. The fertilized ovule develops into a seed. (See p. 298.)

Showy or fragrant flowers are chiefly pollinated by insects, which, seeking nectar, become covered with pollen in one flower and carry it to the next one visited, where some of it is dusted on the stigmas.

Darwin and others have shown that cross-fertilization as a rule produces more vigorous offspring than does self-fertilization. The means by which cross-pollination is effected in plants is of great interest, and many botanists have given much time to its study.

Grasses may be cross-pollinated or self-pollinated. The latter process is more common in grasses than in most other plants. (See p. 300.)

For cross-pollination the grasses depend largely on the wind, which, however, is so wasteful of pollen that, as in all wind-pollinated plants, the amount produced is greatly in excess of the amount used. The wind must carry clouds of pollen in order that a few grains may reach the stigmas (only one grain being needed for the fertilization of an ovule). This over-production of pollen of grasses and some other wind-pollinated plants, especially ragweed, afflicts man with the so-called "hay fever".

There are among the grasses certain habits or structures which favor cross-pollination. In dioecious grasses self-pollination cannot occur. In monoecious grasses cross-pollination is the rule, though self-pollination is possible. The corn plant is a familiar example of the effect of the separation of the sexes on the same individual (monoecism). Under cultivation corn is grown in large areas. The wind carries the pollen from the tassels of one group of plants to the silk of plants lying to the leeward of these but allows little to

settle on the silk of the same plants that furnish the pollen. How little naturally falls in this way is shown by the comparative sterility of single isolated stalks. The cob of such plants usually bears only a few seeds or grains.

POLLINATION OF BLUE GRAMA

Grasses with perfect flowers may show adaptations that aid in cross-pollination. A common grass of the Great Plains known to stockmen as blue grama (*Bouteloua gracilis*) illustrates one of these adaptations. The inflorescence consists of two 1-sided spikes attached obliquely at the upper part of a slender stem about a foot tall. The spikes or flags are about an inch long and an inch apart on the stem. When the wind blows, the spikes are thrown to the lee side. The spikelets are close together on the axis of the spike. At the time of flowering (at anthesis, the botanist would say) the anthers are exerted to leeward on slender filaments. The two feathery stigmas are also exerted but on the windward side. This arrangement practically compels cross-pollination. All the pollen is carried away from the stigmas of the same plant, whereas the stigmas must receive pollen from some other plant.

SELF-POLLINATION

It is probable that many grasses are self-pollinated if cross-pollination fails. Wheat, for example, opens and exposes the anthers and stigmas for only about 15 minutes in the morning. During this time cross-pollination may occur. Some grasses appear to depend mainly on self-pollination, in which case much less pollen is necessary than in the case of cross-pollinated plants. But continued self-pollination (inbreeding) may result in deterioration.

Some kinds of grasses produce flowers that are normally self-fertilized (cleistogamous flowers). One such kind, a rather rare species (*Amphicarpum purshii*) grows in sandy soil of the Coastal Plain from New Jersey to Georgia. It bears a terminal panicle with perfect flowers, but these appear to be normally unfruitful—why, is not at present known. On slender subterranean branches from the base of the plant are borne single large fruitful spikelets that never open, being fertilized by the pollen of their own minute anthers. There are a few other species, curiously enough all American, with similar subterranean cleistogamous spikelets. An example of another kind of cleistogamy is furnished by poverty oatgrass (*Danthonia spicata*), frequent in the eastern United States on sterile soil. The terminal panicle bears a few large spikelets, each with several florets. Hidden in the sheaths at the base of the stem

are self-fertilized cleistogamous spikelets of a single large floret with larger grains, quite different from those of the terminal panicle. At maturity the stem, with its sheath and enclosed grain, disjoints at the node below and can be blown about by the wind. The number of species known to produce cleistogamous spikelets in the lower sheaths is constantly increasing as attention is given to the subject.¹

VEGETATIVE PROPAGATION

Propagation of grasses may be by seed or by various vegetative methods. Annuals depend absolutely on their seeds for the continuation of the species. Perennials are less dependent on seeds since the individual may survive indefinitely. In a general way the perennial grasses may be divided into two groups, the tufted kinds that form crowns, and those that spread by means of rhizomes or stolons.

Rhizomes or rootstocks are creeping underground stems, from the nodes of which upright shoots are produced thus establishing new plants which in turn form more rhizomes. Such plants are likely to be gregarious. They are found mostly in loamy, sandy, or muddy soil where the rhizomes meet with little resistance. In marshes they are constantly extending on the water side and retreating on the land side. The thick growth of the stems allows the deposit of additional material, thus building up soil from the bottom. Finally, the conditions on the land side are less favorable to the growth of the species, and it fails to withstand the competition of other species. Meantime the marsh is being converted into dry land.

SAND-BINDERS

Other rhizomatous species are at home on sand dunes. The best known of these dune grasses is the beachgrass (*Ammophila arenaria*) of Europe, where it is planted extensively to hold drifting sand along the coast. The region now occupied by Golden Gate Park, San Francisco, was once a sterile waste of sand such as is seen along the coast to the south. Beachgrass was imported and set out to hold the sand. After the sand had been fixed by the grass, trees were planted, the soil was enriched, and there has gradually emerged the beautiful park we see there now.

Along the sandy coasts of Europe beachgrass is planted to form the great barrier dunes that protect the land behind. Trees are grown in the lee of the dune, but these cannot withstand the severe conditions of the dune on the side toward the sea. The barrier dunes

¹Those interested may consult an article entitled "Axillary Cleistogenes in some American grasses", by Agnes Chase, Amer. Journ. Bot., vol. 5, p. 254, 1918.

are constantly guarded to repair the inroads of the sea during storms.

In southwestern France there is a region which consisted formerly of alternating sand hills and marshes ill-fitted for agriculture and sparsely populated. This area, called the "landes," lies between the Gironde River and Bayonne. Beachgrass was planted and supplemented by brush fences to hold the sand. In due time a long barrier dune was built up which protected the region behind. In the lee of the barrier dune a forest of pines was produced. Since the reclamation the conditions have so changed that the population has very materially increased.

In the Netherlands a line of dunes extends all along the coast of the provinces of North Holland and South Holland. These are two of the richest provinces in the kingdom, and it is very important to prevent the encroachment of the sea upon the agricultural lands which lie just back of the coast. Beachgrass plantings on the exposed seaward side of the dunes prevent the sand from being blown inland, and forests are planted on the lee side.

Other important reclamation work by means of beachgrass has been done in Denmark, especially on the north coast near Skagen, and in Germany on the Baltic coast. Especially impressive is the work done on the Kurische Nehrung in northeastern Prussia. This narrow sandpit (60 miles long) protects the harbor of the Kurisches Haff, on the east side of which lies Memel. This harbor was formerly endangered by the encroachment of the shifting sand from the dunes. Here again the dunes were fixed with beachgrass, and later all except the exposed sea slope was planted with trees.

Our American species of beachgrass (*Ammophila breviligulata*), found along the Atlantic coast as far south as North Carolina, and around our Great Lakes, is similar to the European species and has been used for holding dunes on Cape Cod and along Lake Michigan.

Beachgrass not only has numerous and vigorous rhizomes but also stems which grow upward as the sand accumulates, never becoming buried.

COASTAL SALT MARSHES

Salt or brackish marshes along the seacoast are made up largely of rhizome-bearing grasses. The plants, of course, will not withstand the battering of the surf, but in the quiet waters of bays and inlets they thrive wherever the rise and fall of the tide is not too great, and where the bottom is sand or mud. Large areas may be occupied by a single species (notably species of *Spartina*, or cordgrass), the rhizomes being so interlaced and so fully occupying the soil that no other kind of plant can gain a foothold.

A notable example of the conversion of shallow water of salt marshes ultimately into dry land is seen on the southern and eastern coast of England, and the continental coast opposite, where *Spartina townsendii* (called "rice grass" in England) has been planted. Great areas are thus being reclaimed from the waters of bays and estuaries. At first there was a fear that the grass would stop up the channels in the harbors and interfere with navigation, but it was soon found that the grass could not grow in deep water; it was therefore an aid to navigation rather than a hindrance.

Throughout our inland regions shallow lakes are being converted into marshes, and these into dry land, by various water plants, prominent among which are grasses (species of *Calamagrostis*, *Leersia*, and *Glyceria* are especially effective).

WEEDS WITH RHIZOMES

Several species of rhizomatous grasses become troublesome weeds. Not only do the plants spread rapidly by the rhizomes, but cultivation serves to propagate the invader, since every joint left in the soil starts a new plant.

Quackgrass (*Agropyron repens*), introduced from Europe, is an example of this group. Johnson grass (*Sorghum halepense*), introduced from the Mediterranean region, is a great pest in our Southern States because of its strong rhizomes. It has one mitigating character, it is good for forage. Johnson grass was originally introduced for forage, but because of its aggressiveness in invading cultivated fields it lost favor with planters in the South. It is now used for forage chiefly in fields that have become so badly infested that they cannot be profitably put to cotton or other cultivated crops. Bermuda grass (*Cynodon dactylon*), also from the Mediterranean region, is a good pasture grass but a bad weed in cotton fields.

STOLONIFEROUS GRASSES

Several grasses propagate by creeping stems above ground, called stolons. Buffalo grass (*Buchloe dactyloides*), dominant over much of the northern and central part of the Great Plains, once formed hundreds of miles of turf, supporting countless herds of bison. Its tough sod, held together by interlacing stolons, was used by the early settlers for making sod houses. In Texas another stoloniferous grass (*Hilaria belangeri*) is dominant on the plains. Rhodes grass (*Chloris gayana*), a forage grass of Arizona, introduced from Africa, produces hard stolons several feet long with internodes as thick as a pipestem.

TUFTED GRASSES

Grasses without rhizomes or stolons grow in tufts, the new shoots arising erect beside the old ones. Such tufts increase in diameter by this gradual accretion at the periphery. If the tufts are very compact the center ultimately dies, since the closely pressed old growth allows no new shoots to appear. There are several grasses on the Great Plains that form such close, regular, circular tufts that they produce "fairy rings." The ring may expand to a diameter of several feet, with a fairly regular border of living plants. For some time the center is so full of old roots and the bases of stems that other plants can get no foothold. Eventually the crowded center dies out, and after many years the ring begins to break up. One then sees a more or less definite circle of tufts among other grasses which meantime have become established. It is probable that some of these rings are more than 100 years old.

SEEDS OF PERENNIAL GRASSES

On the whole, grasses that propagate vegetatively produce a relatively small amount of fertile seed. In some species the power to produce viable seed has been almost lost. This is especially true of sugarcane, the only important cultivated perennial grass that is used for food. The large panicles or plumes contain innumerable flowers but few fertile seeds. Until recently the species was thought to have been cultivated so long by vegetative methods that it had lost the power of producing seed. It is now known that occasional seeds are found, and it is these that are used in obtaining new varieties. By planting a whole plume it is found that now and then seedlings appear.

SEEDS OF ANNUAL GRASSES

Annuals, on the other hand, necessarily produce an abundance of good seed. This is why primitive man chose annual grasses to cultivate for food. All our cereals are annuals, improved by long selection. Perennial grasses that are normally poor seed-bearers could probably be improved by breeding and selection. Timothy, a perennial meadow grass, produces an abundance of good seed. This is one reason why timothy is a leading commercial grass.

The life histories of annuals and perennials differ widely. Annuals depend upon wide dissemination of abundant viable seed to maintain their existence. The seed must be deposited in a favorable situation, must retain its viability, sometimes for long periods, and must germinate quickly under favorable conditions. Therefore, annuals are found primarily in open ground, cultivated fields, soil thrown up by burrowing animals, and in newly formed soil of any kind. Annuals

quickly appear in openings in timber due to fire, to landslides, or to other agencies that destroy the trees previously occupying the space. Banks of rivers or sandbars exposed by receding waters are soon occupied by annuals. Sandy soil in regions of moderate rainfall also furnish a satisfactory substratum for them. When the sand is wet, the seeds germinate quickly, and the plants are often able to produce their own crop of seed before the soil dries out. In desert regions annuals spring up quickly after a rain and mature seed before the effects of the rain have passed. "Six-weeks" grasses of several annual species are abundant after rains in the arid regions of our southwestern States.

PERENNIALS MORE PERSISTENT THAN ANNUALS

Perennials come to maturity more slowly than do annuals and usually do not produce seed the first year. But once established they can hold the ground against annuals. The difficulty of keeping crab-grasses out of lawns composed of perennial grasses may seem to contradict this statement. But a lawn, except in a region of plentiful fogs and drizzle, is a highly artificial creation. The frequent mowing weakens the plants, for it is the foliage that makes the food, and the constant watering causes the roots to spread close to the surface instead of deep into the soil. When crabgrass and yellow bristlegrass take possession of a lawn it is because the perennials fail to withstand the hard conditions and leave unoccupied spots. The countless seeds of annuals are ever present to take advantage of any opening.

GRASSES A DOMINANT FAMILY

Grasses are one of the dominant families of plants. In number of genera and species they are exceeded by the sunflower family (Compositae), the orchids, the legumes, and the madder family (Rubiaceae), but in the number of individuals they probably exceed all other families. They are distributed throughout the world, from pole to pole, and from sea level to alpine summits, wherever there is a substratum (free from snow for a part of the year) on which they can grow. Only in tropical rain forests are they scarce. Here are found several species with broad thin blades that are able to grow in the deep shade. But even in the rain forests narrow-leaved grasses grow in the occasional openings where the light is more abundant. In the American tropical rain forests there are several kinds of climbing bamboos forming beautiful lacy curtains along trails and streams.

Grasses vary in size from an inch to 100 feet or more (giant bamboos). They may be erect, creeping, or climbing. The climbing species have no special organs, such as tendrils, nor do they twine.

However, certain species, especially the so-called "climbing bamboos", reach up through the foliage of trees much as do some kinds of brambles. The stems are prevented from slipping back by rather stiff horizontal or reflexed branches.

The grass family is adapted to a great variety of soils. The species are found in salt- and fresh-water marshes, and in sand, as already described, on rocks, and even in alkali wastes.

The ordinary meadow grasses grow on moderately dry soil, receiving a medium rainfall. Here grow our familiar cultivated species, Kentucky bluegrass (*Poa pratensis*), redtop (*Agrostis alba*), timothy (*Phleum pratense*), orchard grass (*Dactylis glomerata*), meadow fescue (*Festuca elatior*), Bermuda grass (*Cynodon dactylon*), and others. The species may be sod-formers (with rhizomes) or bunch grasses (without rhizomes). Of those mentioned above, Kentucky bluegrass, redtop, and Bermuda grass have rhizomes; the others do not.

DISTRIBUTION

The distribution of grasses in the United States depends largely upon rainfall and temperature. The region from the Atlantic Coast to eastern Nebraska and Texas usually receives sufficient rainfall to produce staple crops, such as corn, wheat, and cotton, and the common meadow and pasture grasses, such as timothy and bluegrass in the North and Bermuda grass in the South. In a general way this area is called the humid region. There is another humid region in the northwestern States from northern California (west of the Sierras) to British Columbia, and east to the Cascades. There are also many small humid valleys in all the western mountain ranges.

Much of the humid region in the East was originally covered with forest. But in the northern and western part there were more or less extensive grasslands called prairies. For example, much of northern Illinois and Iowa was prairie, and the western fringe of the humid region passed gradually from prairie to the vast treeless expanse of the Great Plains.

The wild grasses of the prairie are rather tall species, partly rhizomatous, partly bunch grasses, such as bluejoint turkeyfoot, sometimes called bluestem (*Andropogon furcatus*), prairie beardgrass or little bluestem (*A. scoparius*), Indian grass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*).

The region between the Mississippi River and the Rocky Mountains becomes increasingly dry toward the west. This, the Great Plains, is a dry, nearly level area, increasing in altitude from 1,000 feet to about 6,000 feet at the foot of the mountains. The approximate line of demarkation between the prairie region and the Great

Plains is the 100th meridian. The annual rainfall for the Plains varies from about 28 inches on the east to 16 inches on the west. The grasses of the Great Plains are known as "short grasses" to distinguish them from the "tall grasses" of the prairies. The dominant grass over much of this region is buffalo grass (*Buchloë dactyloides*), mentioned on page 303. In Texas Buffalo grass is partially or wholly replaced by curly mesquite (*Hilaria belangeri*). Blue grama (*Bouteloua gracilis*) and black grama (*B. hirsuta*), both bunch grasses, are also abundant throughout the Great Plains and are excellent forage grasses.

The Great Plains, which extend beyond the boundaries of the United States, far northward into Canada, and southward to merge with the Mexican Plateau, form one of the great grass regions of the world. Other important comparable grasslands are to be found in the llanos (Spanish for plains) of northern South America, the pampas (another Spanish word for plains) of southern South America, the steppes of European and Asiatic Russia, and the high plains of Africa extending from Kenya to Rhodesia.

In the Great Basin, between the Rocky Mountains and the Sierra Nevada, there are large areas with scant rainfall (mostly less than 16 inches annually). These areas are semiarid; or, if the rainfall is very low and the temperature high, they are classed as deserts. The culmination of aridity is found in the Colorado Desert of the lower Colorado River Valley, and the Mohave Desert (including Death Valley) lying to the north. In this desert region the rainfall is mostly below 8 inches.

The grasses of the Great Basin are mostly in widely scattered bunches of highly drought-resistant species of the genera *Bouteloua*, *Aristida*, *Sitanion*, and *Stipa*.

ALKALI GRASSES

There are many areas, especially in the drier regions of the United States, where the soil is so strongly impregnated with soluble salts (alkali) that, even though moist, vegetation is more or less inhibited. Only plants resistant to alkali can thrive under such conditions. As the soluble salts of the soil increase, the number of species diminishes until a point is reached where no vegetation can exist. These salt or alkali (often soda) deserts are found around salt lakes (such as Great Salt Lake) or depressions that are shallow lakes after rains.

The characteristic grasses of such regions not so strongly alkaline or saline as to inhibit vegetation are species of saltgrass (*Distichlis*), alkali-grass (*Puccinellia*), and alkali sacaton (*Sporobolus airoides*).

When the alkali is too strong for vegetation of any kind, the glaring white, usually rather smooth area is colloquially known as a "slick desert."

Salt lakes, salt basins, and alkali depressions are produced by the evaporation from undrained areas. The more soluble salts are dissolved in the soil water during wet periods and left on the surface by evaporation during dry periods.

Certain faulty agricultural practices in irrigated regions illustrate the artificial production of alkali-meadows. In the early days where water for irrigation was plentiful, the ranchmen often allowed an excess of water to flow over meadows to encourage the growth of grass or alfalfa. Unless there was good drainage the soaking brought soluble minerals from below and deposited them at or near the surface as the water evaporated. As the meadows became more and more alkaline the desirable plants gradually disappeared, their place being taken by species more resistant to alkali but less valuable agriculturally. This alkaline condition can be prevented by proper drainage and by supplying water in only such quantity as is necessary.

VARIATION IN LEAF STRUCTURE

The structure of grasses varies with the necessity for resisting evaporation. In regions of abundant rainfall throughout the growing season the grasses have abundant foliage and mostly flat leaf-blades. Of course, the plant must obtain the necessary minerals from the soil by an upward current from the roots. Evaporation from the leaves draws the soil water upward. If the supply of water from the soil does not balance the evaporation from the leaves, the plant wilts. Even in humid regions there is variation in the proportion between absorption and evaporation. Normally, the leaves meet this variation through control of the stomata or breathing pores, which are mostly on the under surface of the blades. These close when the air is dry and open when it is moist.

If the conditions are such that the grasses have difficulty in obtaining from the soil the necessary water, the leaves are structurally different from those grasses that grow in a humid climate. The epidermis is thick and impervious to moisture, so that evaporation takes place only or chiefly through the breathing pores. The blades are often tightly rolled with the breathing pores on the inside. The leaves may be short and clustered close to the ground. In extremely dry regions the plants retreat underground for protection during the dry season, as do herbaceous perennials in winter in humid regions. Life persists in the perennial base beneath the surface ready to send forth shoots after a rain.

Grasses of high altitudes and high latitudes have leaf structures similar to those of desert grasses. The water supply may be ample, but the low temperature of the water and often also of the air interferes with water absorption. The leaves thus have a structure that reduces evaporation to correspond to water supply.

Even in humid regions the water supply may be reduced on rocks or sand, and grasses growing on rocky or sandy soil may have the structure of dry land grasses. The grasses of salt meadows or marshes also have structures that reduce evaporation to meet reduced absorption by the roots. The absorption of soluble salts is hindered more and more as the concentration of the soil water increases.

SEED DISPERSAL

Grasses owe their dominance to their ability to make a living under all conditions where the higher plants can live at all, and also to their ability to reproduce themselves and spread their seeds far and wide. The seeds are often provided with special structures that aid in their dissemination.

The means of dispersal are chiefly wind and animals, though water may play a minor part. Small seeds may be carried by wind great distances without especial adaptive attachments. Some seeds increase their chances of dispersal by wind by having outgrowths of hairs or fuzz. Such seeds are able to remain longer in the air and can be carried further in proportion to their weight than can naked seeds. Examples of this are broomsedge (*Andropogon*), plumegrass (*Erianthus*), and reed (*Phragmites*). The long spreading or reflexed awns of certain species of *Aristida* aid in wind dispersal. On the Great Plains the seeds of *A. longifolia* and allied species may be seen drifting across the surface of the soil in countless numbers. The three spreading awns give a surface upon which the wind acts.

TUMBLEWEEDS

This adaptation to wind dispersal is further developed in tumbleweeds. In a typical tumbleweed the whole plant at maturity is a more or less globular mass of hard stiff branches. The stem breaks off near the ground and the whole plant goes tumbling and rolling before the wind, scattering seed as it goes. Tumbleweeds are characteristic of prairies and plains, as they can function only in open ground.

In grasses it is only the inflorescence that acts as a tumbleweed. Witchgrass (*Panicum capillare*) and ticklegrass (*Agrostis hiemalis*) are examples. At maturity the panicles with their stiff, slender, spreading branches become light, open skeleton balls which break away and roll before the wind.

DISPERSAL BY ANIMALS

Many grasses are adapted to dispersal by animals (including man). The seeds of this class have a covering or appendage which sticks to the wool, hair, or fur of animals, or to the clothing of man. The familiar sandbur has barbed spines for the purpose of attachment. Needlegrasses (*Stipa*) and three-awns (*Aristida*) have seeds with sharp, barbed points that penetrate wool or clothing. The base of the spikelets of *Bromus rigidus* (called ripgut grass by stockmen) is sharp and barbed. The seeds penetrate wool and, much worse, get into the eyes and nostrils of grazing animals, causing serious injury to stock in western States where the grass is often abundant.

DISPERSAL OVER TRADE ROUTES

The methods of dispersal described above account for the spread of species in rather restricted areas. We find, however, that certain kinds of plants, known as weeds, travel widely over the earth. The spread of such plants has been greatly expedited during the last few hundred years. The more rapid rate of travel coincides with the development of the means of transportation by man. Many plants, grasses among them, have been carried along the channels of trade through the agency of man. Some seeds have been carried entirely by accident; others have been carried as impurities in agricultural seed, accidentally, to be sure, but as a part of a direct intention.

Bluegrass (*Poa pratensis*) is not a native of the United States but is now so widespread that, did we not know its history, it would be assumed to be native. From time to time noxious weeds have suddenly appeared in interior States, brought in along with imported seed of alfalfa, cereals, or meadow grasses. When such chance introductions have found favorable conditions for their growth, they have spread and not infrequently have become a menace to crop plants.

USES OF GRASSES

From the standpoint of mankind the primary uses of grasses are as food for man and feed, fodder, or grazing for domestic animals.

The grasses furnishing food for man are the cereals, the most important of which are wheat, corn (maize), rice, barley, rye, and oats. In earlier days other grasses were used, such as millet (*Setaria*), Sorghum, African millet (*Eleusine*), broomcorn millet (*Panicum miliaceum*), Japanese millet (*Echinochloa*), pearl millet (*Pennisetum*), teff (*Eragrostis abyssinica*), certain of the wheat genus (emmer, einkorn, and spelt), forerunners of our modern cultivated forms, and other less familiar grasses. Many of these food

grasses are still in use among primitive peoples. All the species mentioned are annuals and the part used is the seed.

When animals were first domesticated by man in prehistoric times, they depended upon native pasture land for sustenance. Though cattle may graze upon a variety of plants, by far the most important element of pasture lands is the grasses. Only within the last 2 or 3 centuries have grasses been grown for pastures and meadows by sowing the seed of definite species. The seed of many of the cereals is used for stock feed, the most important being corn and, mostly for horses, oats. Corn, of American origin, is now widely cultivated throughout the world.

An important noncereal grass, sugarcane, furnishes food for man, but in this case the juice of the stem is used. This is the only important perennial agricultural food grass. Sugarcane has come into world-wide prominence only within comparatively recent years, though the plant has been cultivated since prehistoric times in tropical Asia.

The cereals and also sugar are the basis of many alcoholic products, much used in the industries and for beverages.

Lawns and the greensward of parks are nearly always made up of grasses. In this country the most important lawngrasses are Kentucky bluegrass and the bentgrasses (*Agrostis*) for the northern States and Bermuda grass for the South. Various forms of creeping bent (*Agrostis palustris*), colonial bent (*A. tenuis*), and velvet bent (*A. canina*) are, in recent years, proving valuable for putting greens on golf courses. Though grasses play a minor role among ornamental plants, plume-grasses (pampasgrass, Ravenna grass, eulalia, and giant reed) are often used in parks to form large showy clumps.

Although bamboos are not very familiar in this country, they enter largely into the life of the peoples of tropical regions, especially in Asia. Some primitive peoples there use them not only for houses, but for practically all household utensils.

RECENT PROGRESS IN AGROSTOLOGY

Our knowledge of grasses is increased by observations made upon living plants as they grow in their native habitat, by studies of dried specimens in herbaria, where plants from different regions may be compared, and by anatomical investigations with the microscope in the laboratory.

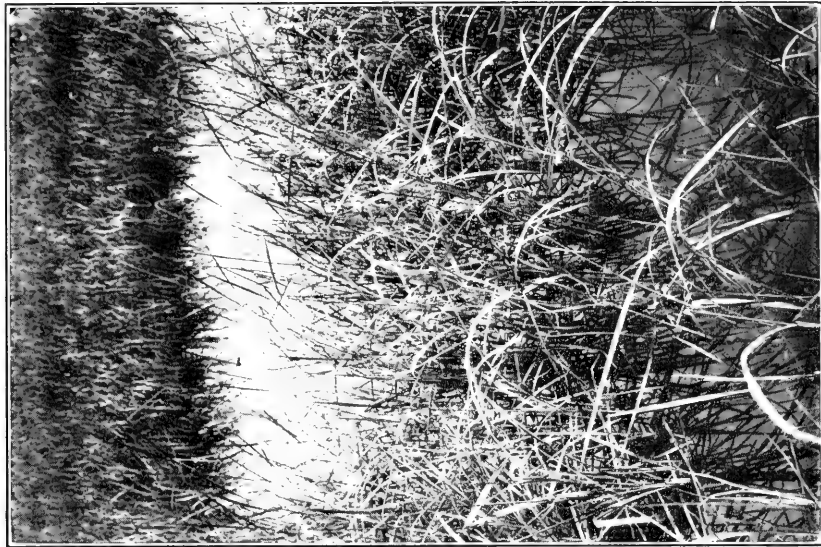
A recent expedition to Brazil has resulted in important additions to our knowledge of that region. Jason R. Swallen, assistant agrostologist, spent 8 months in northeastern Brazil, studying and collecting grasses for the National Herbarium. He visited the states

of Pará, Maranhão, Piauhý, Ceará, and Rio Grande do Norte, a part of Brazil in which few botanical collections, especially of grasses, have been made. In much of this area the chief means of transportation is by rivers which flow from south to north. To reach the grassy savannas of the interior Mr. Swallen was obliged to travel hundreds of miles on muleback. The result was a fine collection of grasses now being studied at the National Herbarium. The notes on habit, distribution, and habitat are important aids in determining the systematic relation of the species.

The collections made by trained agrostologists are especially valuable additions to the section of grasses of the National Herbarium, which now contains the largest number of specimens of grasses of any herbarium in the world, the number of sheets being more than 210,000.

The classification of plants is an attempt to show systematic or genetic relationships. In many cases the relationship is obvious, but there are groups which cannot be placed with assurance in a system of classification. Not infrequently the systematic position of a genus (for example) is clarified by a study of developing organs, the internal anatomy of tissues, or the germination of the seeds. Recently, there has been published a work² which bears strongly on the classification of grasses. By a microscopical study of the early stages in the development of the inflorescence of certain grass genera (*Setaria*, *Pennisetum*, *Cenchrus*), Dr. Arber has shown the morphological similarities of the bristles, spines, and involucre bracts which at maturity appear so diverse. She has investigated the rhizomes of bamboos, the corms of *Arrhenatherum elatius* var. *bulbosum*, and the inflorescence of *Hordeum*. She reviews the work done upon Indian corn or maize by Collins and others in this country and adds many observations of her own upon this remarkable grass. *Spartina townsendii* (see p. 303) has received her attention, and she lends the weight of her opinion to the theory that the species is of hybrid origin. Many other morphological puzzles have been studied in this important book.

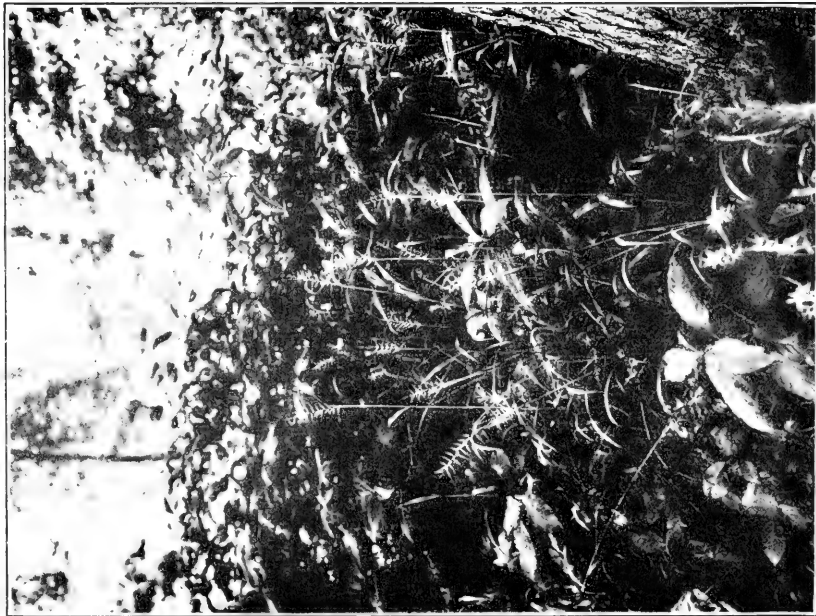
² Arber, Agnes, Gramineae, a study of cereal, bamboo, and grass. Cambridge University Press, 1934.



1. A marsh grass, Indian rice (*Zizania aquatica*), which is helping to convert a marsh into dry land.



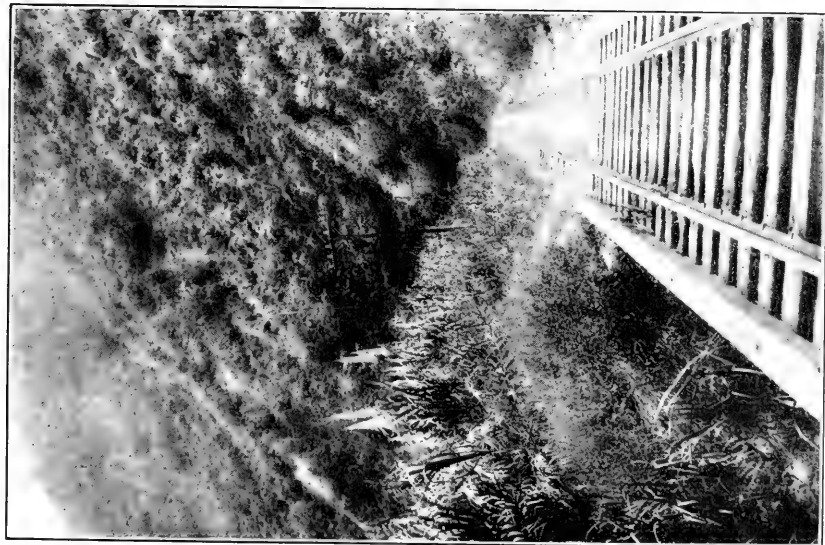
2. A grass with fluffy seeds adapted to be dispersed by the wind. Locally known as foxtail (*Andropogon bicornis*). St. Croix, West Indies.



1. Bottlebrush (*Hystrix patula*), a native grass of the eastern United States, sometimes cultivated for ornament. The individual spikelets can be seen in two ranks on a central axis.



2. Elephant grass (*Pennisetum purpureum*), common in central Africa. This is being introduced for forage into tropical America and into southern Florida where it is called Napier grass.



1. A large plumegrass (*Glycerium sagittatum*) forming dense thickets in moist places. Along the railroad from Guayaquil to Quito as it enters the mountains. Occasionally cultivated in greenhouses as uva grass.



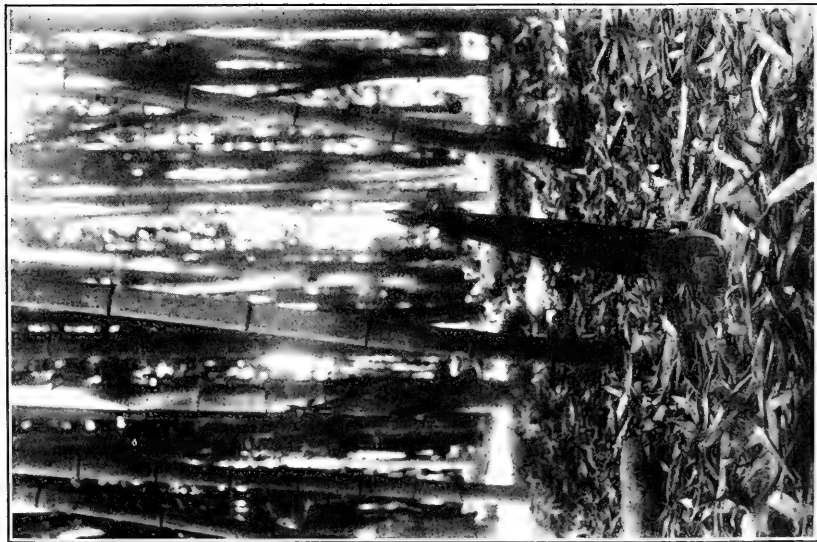
2. Single plants of uva grass (*Glycerium sagittatum*). Near Colonia Perené, Peru, on the eastern slope of the Andes.



1. A lawn of Kikuyu grass (*Pennisetum clandestinum*), Nairobi, Kenya. Residence of the Governor. This grass is now being tried in southern United States and gives promise of success.



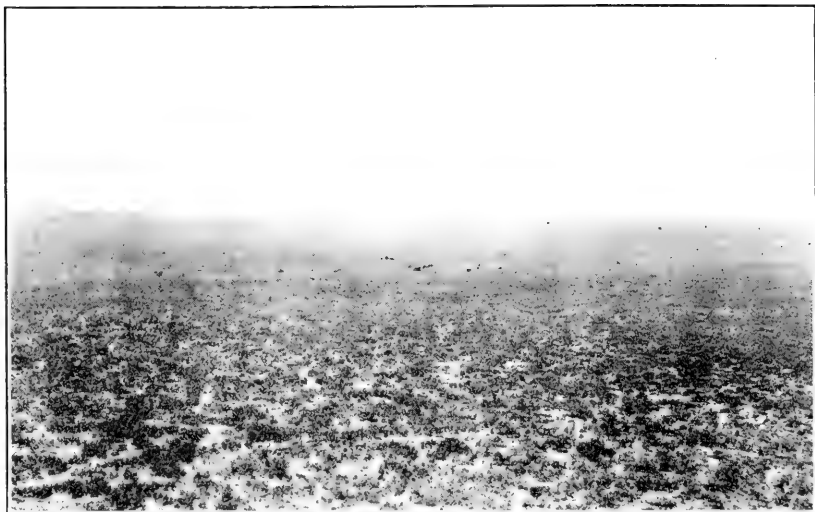
2. Bunch grasses, mostly ichu (*Stipa ichu*), on the high plain of central Peru near Chuquibamilla, altitude about 13,000 feet. At the onset of snow squalls the young lambs immediately take refuge beneath their mothers.



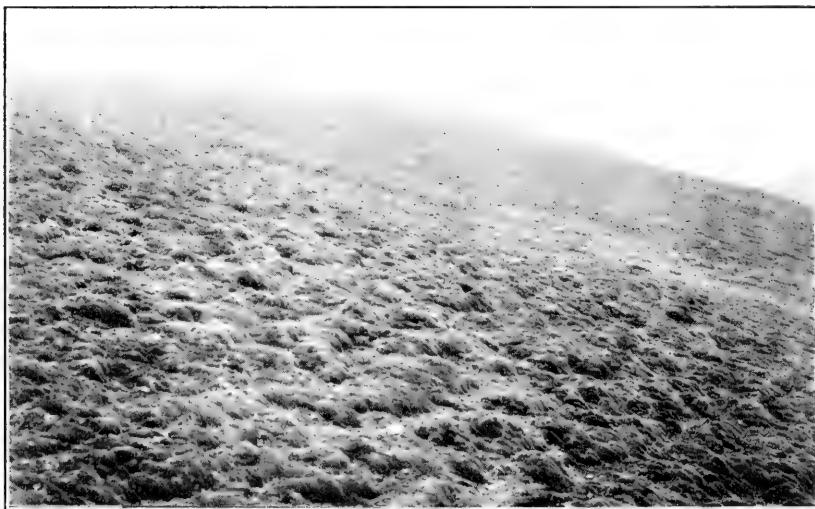
1. A clump of bamboo showing a sprout. The young stem comes from rhizomes and is as large in diameter as it will be when fully grown. The stems of bamboos do not increase in diameter like most other trees.



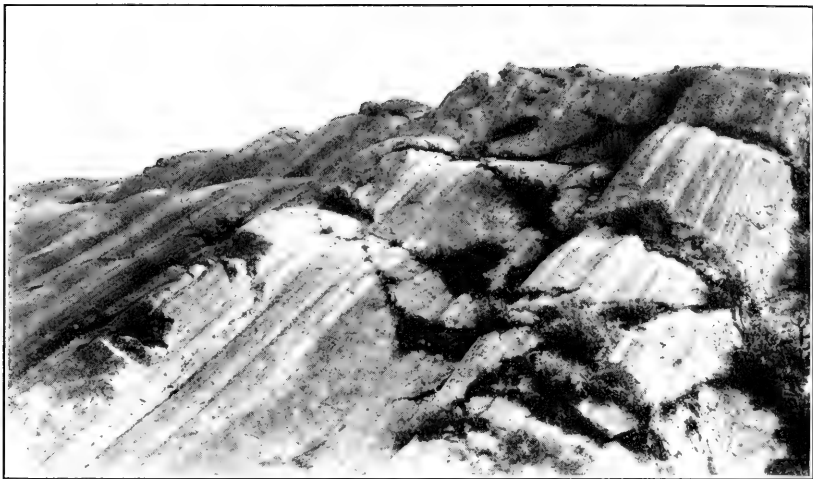
2. A house with walls of bamboo board. The large stems are partially split and flattened out, forming a board. Near Mount Chimborazo, Ecuador. The guide wears the usual native wooden poncho.



1. Great Plains near Amarillo, Texas. In this semiarid region the "short grasses" are in bunches with unoccupied areas between and do not form a continuous turf. Mostly species of *Aristida*.



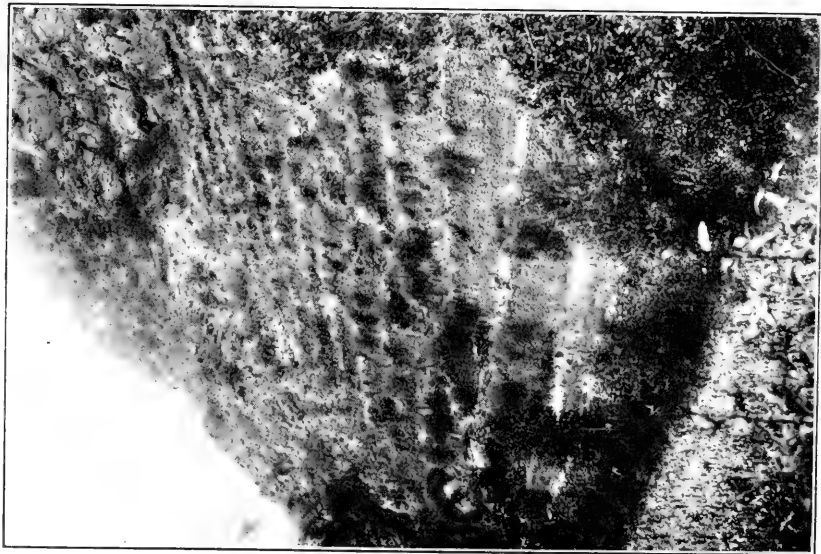
2. A peculiar tussock grass (mossgrass, *Acicahne pulvinata*) which forms dense hard bunches scarcely to be recognized as a grass. Hills around Cerro de Pasco, Peru; altitude about 14,500 feet.



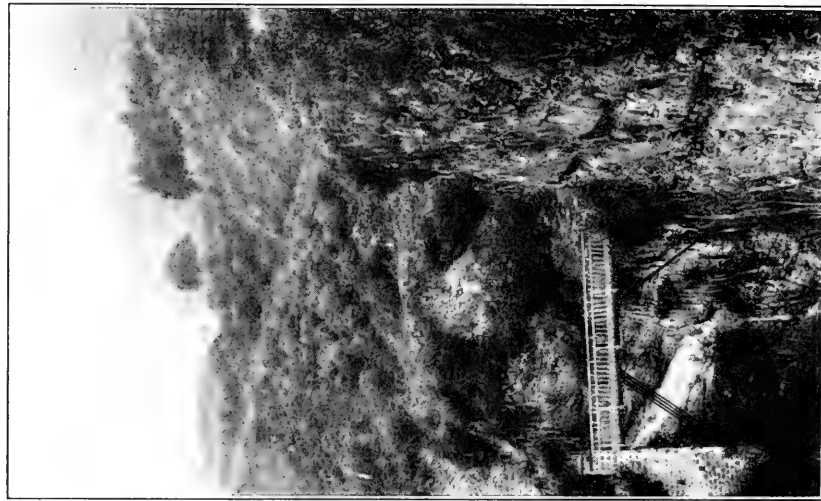
1. Grasses growing on rocks, the soil accumulating in crevices. A ridge of rock between the quarry and the Inca fort, north of Cuzco. The grooves appear to have been made by the dragging of the stones over the ridge.



2. A typical mountain bunch grass, Mount Chimborazo, Ecuador, altitude about 15,000 feet. The spaces between the bunches (species of *Festuca*) are fully occupied by other plants. Bog with tussock plants in foreground.



1. Grasses that are at home on rocks. The terraces (now partially ruined) were made by the Incas. In each level area between the walls good soil was placed in which crops were raised. Near Ollantaytambo, north of Cuzco, Peru.



2. Grasses growing on vertical cliffs. Near Baños, Ecuador.

PHOTOTROPISM: A SPECIFIC GROWTH RESPONSE TO LIGHT

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[With 2 plates]

Psychologists and physiologists have shown that the human eye is most sensitive to yellow and becomes less and less sensitive to light of longer and shorter wave lengths as one passes toward the red and the blue, respectively, of the visible spectrum. In other words, when all the colors of the spectrum are of equal intensity, yellow looks the brightest to the human eye. Of the entire range of radiant energy, only that falling between the approximate limits 4,000 and 7,600 angstrom units is visible to the average human eye. However, longer radiation in the infrared can be detected by a sensation of warmth on the skin, and if the skin is exposed to certain short radiations in the ultraviolet, a temporary burning results. Experiments with animals such as the honeybee and a number of unicellular organisms have shown other ranges of sensitivity than that found in man. The question arises: To what wave lengths of radiant energy are plants sensitive?

There are a number of structures in plants which distinctly indicate a mechanism that responds to light. In certain dimly lighted caverns there is found a small moss, *Schistostega osmundacea*, whose protonema consists of a layer of lens-shaped cells so constructed that light gathered over a relatively large area is concentrated onto a few chloroplasts located in the bottoms of the cells. In the leaf cells of other plants the chloroplasts arrange themselves differently under different light intensities. The chloroplasts are the small bodies in green plants that bear the chlorophyll, the substance essential to life. When the light is weak, these chloroplasts spread out at right angles to the rays of light and are thus able to intercept more light. If, however, the light is very strong, these same chloroplasts arrange themselves along the cell walls that are parallel to the light rays, thus intercepting a small fraction of the light. Another light-response reaction with

which everyone is familiar is the bending toward the light of common house plants that are grown on window ledges. The necessity for turning them from day to day in order to have them grow symmetrically is common knowledge. All these examples illustrate the fact that plants are sensitive to light and that they have a definite light-response.

The lop-sided growth of a potted window plant such as a geranium is an indication that the external conditions conducive to growth are not symmetrical. Although the temperature and humidity of the air may be the same on all sides of the plant, the light conditions are decidedly different. Those portions of the plant next to the window receive more light than those toward the darker interior, and the plant grows toward the more intense light. The phenomenon of unsymmetrical growth due to unilateral light conditions has been used by plant investigators to determine the sensitivity of plants to light. This response is known as phototropism.

From a superficial observation it would appear that light hinders or retards elongation of plant cells. It is frequently noted that the stems of many plants grow more rapidly at night than during the day. Potatoes send forth greatly elongated shoots in a darkened cellar; if these same potatoes were permitted to remain in strong light, the sprouts would be very much shorter and the internodes greatly reduced. In the case of plants illuminated on one side it is noted that the shaded sides of the stems have stretched more than those receiving direct illumination. The uneven rate of growth on the opposite sides results in curved stems and a general appearance of the plant turning toward the light.

Although superficial observations clearly indicate that the sensitivity of the plant toward radiant energy is such that it reacts differently to light and darkness, the question as to its sensitivity to different colors or wave lengths of light is not so readily answered. To obtain an answer a plant might be placed half-way between two equally intense lights, for example blue and green, to ascertain toward which one the plant bends. The plant's sensitivity to different colors could thus be determined in a general way and compared to the sensitivity of various animal reactions or even to human vision.

There is abundant evidence that phototropism is a special case of the more general light-growth phenomenon in plants, and that intensity as well as wave length and duration of radiation must be carefully considered. In phototropic experiments the specific characteristics of the plant must be known. The regions sensitive to light are frequently localized. The plant's response is sometimes positive, that is, bending toward the light; sometimes negative, bending away from the light, and again it may even change from positive to nega-

tive. Furthermore, it has been shown in recent years that there are present in the plant specific growth substances which are directly associated with this light-growth response.

The foundation of much of the recent work on phototropism was laid by the Dutch investigator, Blaauw. Perhaps the first quantitative measurements and physical interpretations were made by him and published in 1909. The responses of young seedlings were studied in different regions of the spectrum, and the energy values were calculated from Langley's tables. For oat seedlings Blaauw found the most effective region of the carbon arc spectrum to lie between 4,660 and 4,780 Å, whereas the red and yellow regions were ineffective. The minimum amount of radiation required to produce phototropism was 20 meter-candle seconds. Furthermore it appears that for equal effects the product of light intensity and duration of exposure is a constant.

Dillewijn, another Dutch investigator, has shown in a very interesting manner that the phototropic response of a plant can be predicted by knowing how it grows in light of different intensities. He thus shows that phototropism is a light-growth response, as brought out by Blaauw's theory. Using oat seedlings, Dillewijn determined the rate of growth in several different "quantities" of light and also for those of one-thirtieth the value. He had calculated that the light falling on one side of a seedling was reduced to one-thirtieth of its intensity after passing through to the opposite side. This value, of course, varies with the plant used.

The results of Dillewijn's experiments are reproduced in figure 1. The abscissa represents time in hours, and the ordinate the rate of growth expressed as μ per minute ($\mu = 0.001$ mm). The light intensity is indicated on the right in meter-candles. The arrow represents the time of illumination, with the duration noted above in seconds.

Each pair of curves represents two light "quantities", one one-thirtieth of the value of the other shown as the lightly and heavily drawn lines, respectively. In the *d* pair of curves the side of the seedling next to the source of illumination (heavy line) is retarded more than the far side (light line), which results in a positive bending for this weak light quantity (80 and 2.5 meter-candles for 10 seconds). With a greater quantity of light (2,400 and 80 meter-candles for 10 seconds), as illustrated by the pair of curves in *c*, first a positive then a negative bending would occur. A further increase (2,400 and 80 meter-candles for 90 seconds) will again bring about a positive bending as in *b* which becomes less as the quantity is increased, as shown graphically in *a* (2,400 and 80 meter-candles for 15 minutes). These predicted growth curvatures correspond to real curvatures that have been found, and they indicate that with

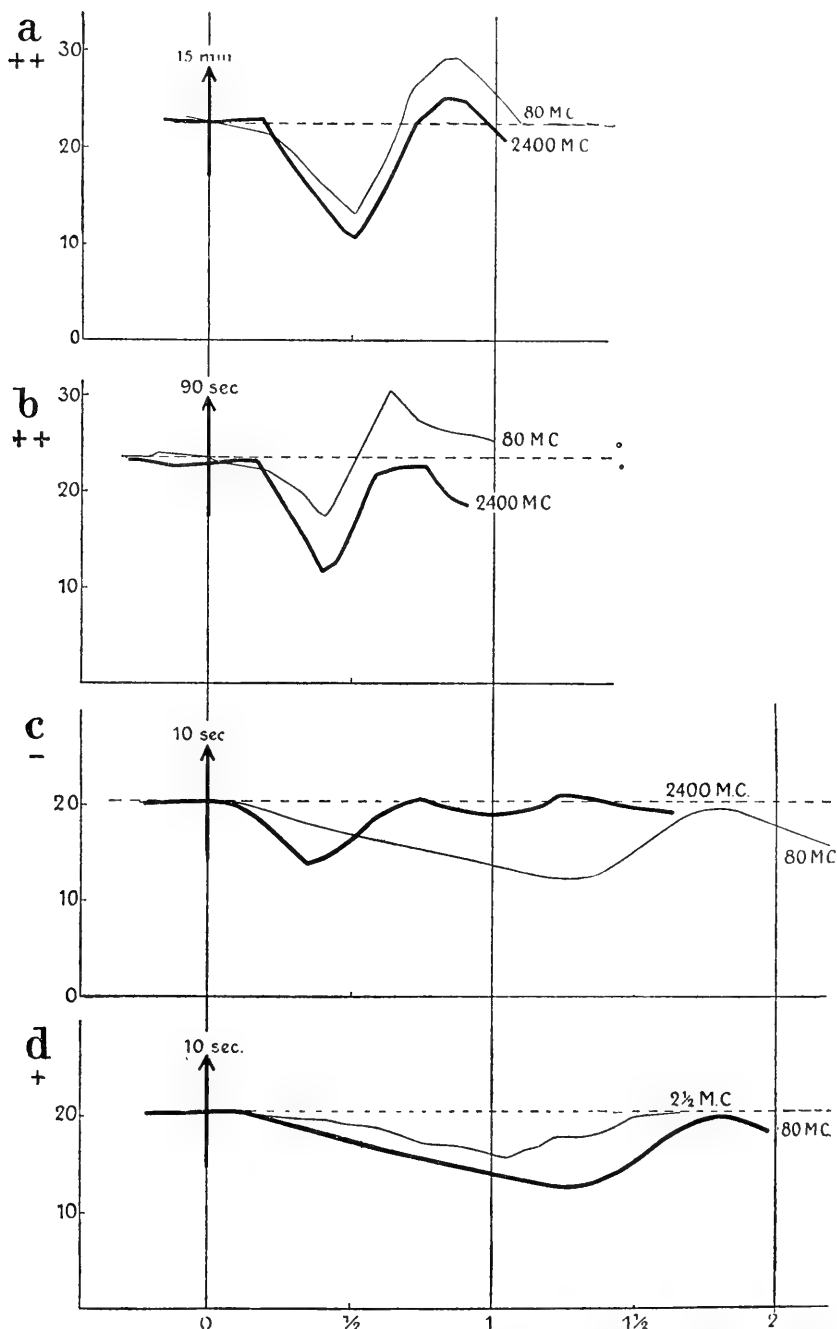


FIGURE 1.—Graphs from Dillewijn showing growth of *Avena sativa*. Abscissa represents time in hours and the ordinate rate of growth in μ per minute. The intensity of light is indicated in meter-candles. The light line represents the growth response for $\frac{1}{30}$ the light intensity of that bringing about the response shown by the heavy line. The arrow indicates the moment of illumination with the duration marked above. The predicted phototropic response is indicated by plus and minus signs.

low light intensities over long periods of illumination no negative curvatures are found.

This work of Dillewijn, as well as that of others, shows that light within a certain range of intensity brings about a decreased growth rate, whereas that of another range results in an increased rate of growth. It has been shown that the greater the "quantity" of light (intensity times duration of exposure), the shorter the reaction time becomes. Thus in *a* with the greatest quantity of light

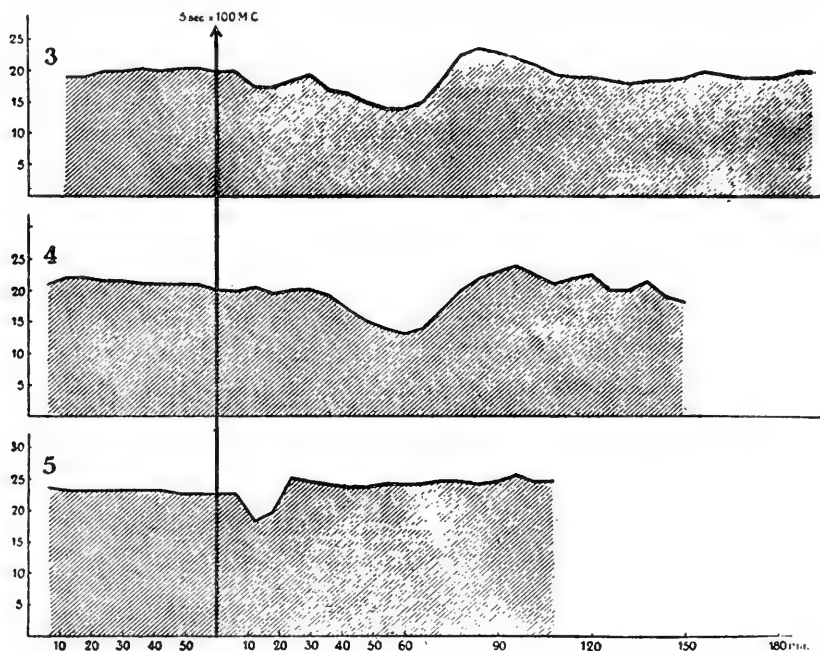


FIGURE 2.—Graphs from Went showing light-growth response of *Avena*. The abscissa represents time in minutes, the ordinate growth in μ per minute, and the arrow the moment of illumination.

Upper graph: Illumination of entire coleoptile (12 mm long).

Middle graph: Illumination of the tip (1.25 mm).

Lower graph: Illumination of base (9 mm) while the top (3 mm) was kept in darkness.

the greatest decrease in growth rate is reached in half an hour, while in *d* with the least light quantity the minimum is reached in about $1\frac{1}{2}$ hours.

In much of the work with the coleoptile its entire length was exposed to light. It has been found, however, that the extreme tip is the most sensitive of the entire tissue. Went is of the opinion that there are two distinct growth responses—the tip response and the base response. His data, shown graphically in figure 2, are of interest in connection with other work where positive and negative curvatures are obtained with different light intensities.

In the upper graph of figure 2 the entire coleoptile is illuminated. In the middle graph only 1.25 mm of the tip is illuminated, and in the lower graph only the base, 9 mm in length, receives light. The abscissa represents the time in minutes and the ordinate the growth in μ per minute. The arrow represents the point of illumination for 5 seconds by a light intensity of 100 meter-candles. In the second and lower graphs the first effect is seen to be a retardation in growth followed by an acceleration. When only the base is illuminated, as shown in the lower graph, minimum growth rate occurs after 16 minutes. When the illumination is confined to the tip, the minimum occurs after about an hour. The growth responses following tip and base illumination is reflected in the response of the coleoptile which is illuminated along its full length (upper graph). The position of the minimum depends on temperature. A somewhat lower temperature delays the time of minimum growth rate. Also, the duration of the illumination is a factor to be considered.

This complex relationship existing between the plant and light is further complicated by the discovery in recent years of a growth-promoting substance formed in the tips of coleoptiles, which controls their growth. When this substance diffuses from the tip into the elongating portion of the sprout, growth is accelerated. It is possible that light either prevents the formation of this growth substance, destroys it, or changes its direction of diffusion. A number of investigators support the theory that phototropic curvatures arise as a result of auxin being transported sideways from the illuminated side toward the shaded side of the coleoptile. Went, of Utrecht, and his school perhaps have contributed more to this phase of phototropism than any other investigators. Their experiments are most interesting. In some of this work the tips cut from a number of coleoptiles were placed on a thin sheet of gelatin with the cut surface next to the gelatin. After an hour these tips were removed and the gelatin cut into small blocks. These blocks were then placed asymmetrically on the freshly cut surfaces of decapitated coleoptiles. In 3 hours these decapitated coleoptiles showed a very marked bending with the blocks on the convex sides. (See fig. 3.) Control blocks not previously treated with the growth substance produced either no bending or very slight positive curvature.

It has been found that under certain conditions the curvature is proportional to the amount of growth substance supplied. If the angle of curvature is 10° , the growth effect has been called an *Avena* unit (AU). In order to place all data on a quantitative basis, Dolk and Thimann suggest as the unit that quantity of growth substance which has to be present in 1 cc of solution to give, when mixed with 1 cc agar, an angle of 1° after 110 minutes.

The question arises as to what influence light has on these growth substances. By illuminating the coleoptiles with different quantities of light from 0 to 1,000,000 MCS (meter-candle seconds) and impregnating gelatin with substances from these tips and studying the curvatures produced on decapitated coleoptiles, Went shows the possibility of imitating phototropic bending. In his own words:

I first placed, as in all former experiments, on one side of the stump gelatin treated with tips to which an illumination of, e. g., 100,000 MCS had been applied. Then on the other side a gelatin block was placed, on which the

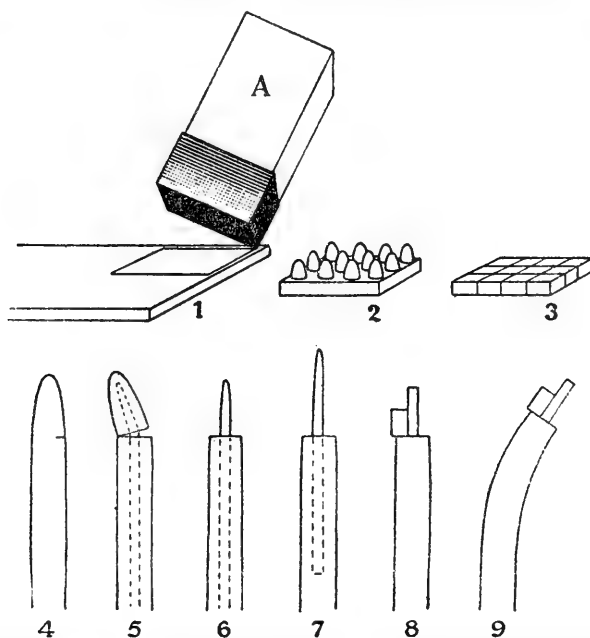


FIGURE 3.—(From Went). Schematic preparation of the analysis of growth substances. 1. Agar plate stamped from sheet of agar. 2. Coleoptile tips placed on agar plate. 3. Agar plate divided into twelve cubes. 4. Coleoptile tip cut on one side. 5 and 6. Removal of tip. 7. Primary leaf pulled out. 8. Agar cube placed unilaterally on coleoptile. 9. Curved growth response of plant.

tips had stood that had been illuminated with 10 times less light. In this way a gelatin system was placed on the stump which, according to Blaauw's theory, as nearly as possible approached the unilaterally illuminated tip. The plantlets indeed bent themselves in perfect accordance with the figures obtained by Arisz. With a difference of 1,000 versus 0 MCS a positive curvature (in 7 out of 9 plants, 2 remained straight) occurred, reckoned toward the 1,000 MCS. With 10,000 versus 1,000 MCS the curvature was negative. With 100,000 versus 10,000 MCS I found a positive curvature again, i. e., towards the 100,000 MCS. It appears that the retardation in growth obtained by van Dillewijn with an illumination of 800 MCS and the acceleration with 80,000 MCS was the result of a smaller and larger formation of growth-promoting substances, respectively.

Went concludes that—

The influence of light on a coleoptile of *Avena* therefore appears in this investigation as in the former to be twofold: in the first place, it has an effect on the formation of growth-regulators in the tip; and, secondly, it temporarily diminishes the transport-rate of the growth regulators.

Chemical studies have been made to determine the composition of these growth substances (*auxins*), which have also been found in mushrooms, in the "mash" obtained in the process of making alcohol by fermentation of molasses, and in yeast. A much richer source of auxin has been found to be human urine. Kögl and his collaborators have reported the chemical properties of three growth substances (*auxins*) which they have succeeded in isolating. These are: Auxin *a*, $C_{18}H_{32}O_5$; auxin *b*, $C_{18}H_{30}O_4$; and hetero-auxin, β -indolyl-acetic acid, $C_{10}H_9O_2N$. Auxin is an unsaturated acid which loses its growth-promoting activity by oxidation. Auxin *a* is stable in acid and destroyed by alkali, auxin *b* is destroyed by acid and by alkali, and hetero-auxin is stable in alkali and destroyed by acid.

From the above discussion it is apparent that light exerts an important influence on this growth-promoting substance. White light is composed of all the wave lengths in the visible spectrum. The interesting question that arises is, What particular wave lengths modify the activity of auxins or deflect their transportation in plants, thereby bringing about asymmetric growth? The question is directly related to phototropism in colored light, that is, light of restricted wave lengths. One way of attacking the problem has been to study the sensitivity of oat seedlings to light of accurately defined wave-length limits. Experiments of this type are being conducted by the Smithsonian Institution.

The general procedure used in studying the wave-length effects in phototropism is to place an oat seedling between two different lights. (See pl. 1.) After a time interval the seedling is examined for a one-sided growth. If, for example, when the seedling was exposed to blue light on one side and to green on the other, a distinct bending was noted toward the blue light, it was then known that the blue light exerted a greater retarding action, since the side of the seedling toward the green light grew more, thus bending the seedling toward the blue light. The appearance of such a seedling is shown in plate 2. The lights were then so adjusted as to increase the green, or decrease the blue intensity. Another seedling was used and the process repeated until a balance point was obtained where the effect of one light neutralized the effect of the other. When this point was determined a specially constructed thermocouple replaced the seedling,

and by means of a galvanometer the two light intensities were measured.

From a number of such experiments the curve shown in figure 4 was constructed. This curve illustrates the sensitivity of the oat seedling (plotted vertically) to the wave lengths of light (plotted horizontally). The sensitivity increases rapidly from 4,100 Å to 4,400 Å, then falls off somewhat to about 4,575 Å, and again rises to a secondary maximum at about 4,750 Å. From this point the sensi-

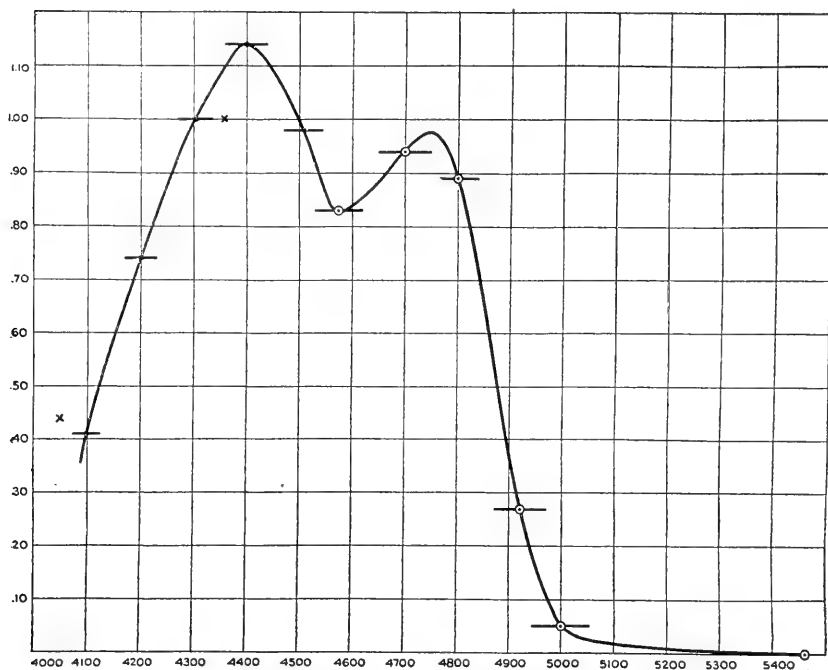


FIGURE 4.—Phototropic sensitivity curve of oat coleoptile for the wave-length bands represented by the horizontal bars.

tivity decreases rapidly to 5,000 Å, from which point it gradually tapers to 5,461 Å, the threshold of sensitivity on the long wave-length side. Briefly, it can be concluded that the region of greatest sensitivity is in the blue. That is, growth is retarded the most in the blue light. Orange and red light have no effect in retarding the growth of these oat seedlings.

It is interesting to compare the wave-length sensitivity of the oat seedling to other light-sensitive organisms and to photoelectric substances. In figure 5 the relative reaction curve of the honeybee to color, the relative visibility curve of the human eye, and the relative spectral response of a Weston photronic cell are plotted, to-

gether with the relative phototropic curve of the oat coleoptile. The maximum sensitivity of the human eye and of the bee falls at practically the same wave length, about 5,600 Å. The bee can detect blues somewhat better than man, but the human eye is more sensitive in the red end of the spectrum. The entire sensitivity curve of the oat is shifted toward the blue in comparison with the other curves, its maximum being at about 4,400 Å. As mentioned above, wave lengths longer than 5,000 Å in the visible spectrum exert but

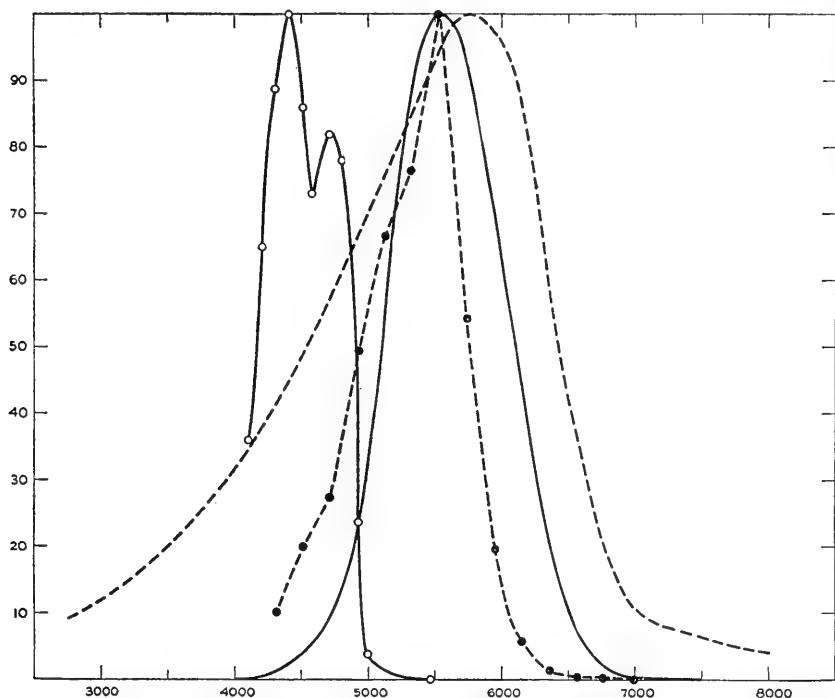


FIGURE 5.—Relative phototropic sensitivity of the oat seedling (continuous curve with open circles) compared to the relative sensitivity of the honeybee (dash curve with solid circles), the human eye (continuous curve) and a Weston photronic cell (dash curve) in the spectrum. Wave lengths are indicated in Angstrom units.

little influence on the growth response of the plant. The photronic cell curve has its peak farthest toward the red end of the spectrum but approximates rather closely the peak of the human eye curve. It has a much broader range than the other sensitivity curves. This means that this particular cell can detect light in the red end and the violet end of the spectral range which neither the human eye, the honeybee, nor the oat plant can detect.

The growth movement of plants known as phototropism is closely related to auxin, which some investigators claim is a true hormone.

The reason for such a claim is that there is no proportionality of relationship between the very minute amounts of this substance used and the enormous transformations that take place. It is also evident that phototropism is directly related to the duration, intensity, and wave length of light. With increasing understanding of these various phases of the problem, we are getting a clearer picture of the mechanism of plant growth and its bearing upon the welfare of man and some of his economic problems.

SELECTED BIBLIOGRAPHY

BERTHOLF, LLOYD M.

1931. Reactions of the honeybee to light. Journ. Agr. Res., vol. 42, pp. 379-419.

DU BUY, H. G., and NUERNBERGK, E.

1932. Phototropismus und Wachstum der Pflanzen I. Erg. Biol., vol. 9, pp. 358-544.
1934. Phototropismus und Wachstum der Pflanzen II. Erg. Biol., vol. 10, pp. 207-322.

JOHNSTON, EARL S.

1931. The dependence of plants on radiant energy. Smithsonian Sci. Ser., vol. 11, pp. 287-315.
1934. Phototropic sensitivity in relation to wave length. Smithsonian Misc. Coll., vol. 92, no. 11, pp. 1-17, 2 pls.

KÖGL, FRITZ.

1933. On plant growth hormones (*auxin-a* and *auxin-b*). Rep. British Assoc. Adv. Sci., 1933, pp. 600-609.

MAST, S. O.

1911. Light and the behavior of organisms. New York. 410 pp.
1917. The relation between spectral color and stimulation in the lower organisms. Journ. Experimental Zoology, vol. 22, no. 3, pp. 471-528.

PRIESTLEY, J. H.

1926. Light and growth. III. An interpretation of phototropic growth curvatures. New Phytol., vol. 25, pp. 213-226.
1926. Light and growth. IV. An examination of the phototropic mechanism concerned in the curvature of coleoptiles of the gramineae. New Phytol., vol. 25, pp. 227-247.

WENT, F. A. F. C.

1935. The investigations on growths and tropisms carried on in the botanical laboratory of the University of Utrecht during the last decade. Biological Reviews, vol. 10, pp. 187-207.

WENT, F. W.

1928. Wuchsstoff und Wachstum. Rec. Trav. Bot. Néerl., vol. 25, pp. 1-114.
1935. Auxin, the plant growth-hormone. Bot. Rev., vol. 1, no. 5, pp. 162-182.



GENERAL VIEW OF APPARATUS USED IN DETERMINING EFFECT OF WAVE LENGTH ON GROWTH CURVATURES OF YOUNG SEEDLINGS.
The seedling is placed in a vertical position in the cylinder within the centrally located box and illuminated from each side.



PHOTOTROPIC CURVATURE OF AN OAT SEEDLING RESULTING FROM A DIFFERENCE
IN WAVE LENGTHS OF LIGHT ILLUMINATING IT FROM OPPOSITE SIDES.

AN OUTLINE DEVELOPMENT OF HIGHWAY TRAVEL, ESPECIALLY IN AMERICA

By CARL W. MITMAN

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Museum*

[With 12 plates]

I

For the past several hundred years Mother Earth has been the subject of a great amount of scientific study. The geologists have determined, for one thing, that long ago she experienced several periods of intensely cold weather and that great portions of her surface were covered with enormous thicknesses of snow and ice. The last of these cold periods, or Ice Ages, reached its peak in Europe and Asia about 40,000 years ago; then the weather began to moderate by infinitesimal degrees, and by about the year 8000 B. C., after 30,000 years of slow melting, the ice disappeared except around the North and South Poles. Again, the biologists and anthropologists have found that a number of breeds of animals, as well as man, whose life began hundreds of thousands of years before the Ice Ages, were hardy enough to survive the intense cold, and that in spite of the great hardships he had to endure, man developed physically and mentally and was a far superior being after the Ice Ages than before.

Some idea of the appearance of the people living during and following the last Ice Age may be had from the family group pictured in plate 1. It is hard to believe that such brutish-looking individuals possessed any mentality whatever, and yet they were the most intelligent creatures inhabiting the earth at that time, some 20,000 to 40,000 years ago. They cooked their meat; they knew how to tie things together with strands of grass and other natural fibers; and they possessed stone tools of their own manufacture, including hammers, axes, knives, saws, and drills. Mother Nature, too, gave them great physical strength, and with the help of a stone-headed bludgeon the men were able to protect themselves and

their families from the wild animals and, when necessary, kill them for food. Their life was one of continual wandering, remaining in any one place only so long as the hunting and fishing continued plentiful, and temporarily living in the mouths of caves. Such was man's existence for millennia, but, as in the case of his ancestors, he continued to develop by imperceptible degrees, both in physical and mental make-up. In fact, whole races of man disappeared, and others took their places on the earth, and each successive race was superior to the last.

Man's staple food 10,000 years ago was fresh meat, and from his long association with animals he had acquired a fund of knowledge of their habits and ways, which he cunningly applied in hunting them. His stone weapons were best suited for hunting in the open country, and he quite naturally came to know best the animals ranging the grassy terrains, such as pigs, sheep, oxen, and horses. Through following the herds on their seasonal migrations and occasionally capturing and tending stray animals, man acquired additional knowledge of the various breeds and gradually became a cattle herder and breeder. In this way each successive generation of animals became more tame and accustomed to man, and by about 6,000 B. C. many of the grass-eating varieties were about ready for complete domestication. This came about by slow degrees in the subsequent centuries, with man at the same time gradually changing from a nomadic hunter and herder to a settled agriculturist with horses and cattle to help till the soil. Anthropologists are generally of the opinion that this great change in man's life took place in the interior of Asia, for somewhere in this region was the cradleland of the human race. It might have been in the plains area east of the Caspian Sea, where grasslands abound and where horses and cattle would naturally congregate.

As a settled, peaceful farmer with a lessened struggle for subsistence and more time to think, man was bound to develop new ideas such as ways of making better-edged tools, skinning and curing hides, sewing garments, and making ornaments, and there is no doubt that some fellow tried experiments with his trained animals such as tying a pack on a dog's or a horse's back. When this was successfully accomplished, one can easily imagine the confidence with which some other chap attempted the next obvious step—that of riding the animals. He succeeded in this, too, first on oxen and donkeys, about 7,000 years ago, and in doing it he provided the first real medium of transportation. It was on horseback and in ox teams that the hordes of Huns—the last of the great migrations—invaded and overran Europe. In the ages which followed, many kinds of animals, such as the camel and the elephant, were trained both as burden bearers and

as human carriers, but the horse continued to be, because of his fleetness of foot, man's favorite personal carrier.

II

In 1914 Berthold Laufer¹ wrote:

Whatever our modern progress in the perfection of land transportation may be, whether we consider our steam-engine or motor cars, they all depend upon the basic principle of the wheel—that wonderful invention of prehistoric days, of the time, place, and author of which we are ignorant.

Archeological researches have yielded no evidence as to the inventor of the wheel, and it is unlikely that any evidence will ever be found because of the great antiquity of the invention. Egypt had neither the horse nor the wagon until they were introduced by invaders from the East about 3500 B. C. Europe knew nothing of the wheel, the plow, or domesticated animals until well in the Bronze Age, approximately 1500 B. C., and it was about this same time that China first heard of them. It is quite reasonable to assume, therefore, that the wheel and cart were devised in Asia, possibly about the time, 8000 B. C. to 6000 B. C., that man first taught the horse to drag his plow for him.

There are two schools of thought regarding man's discovery of the wheel. Both schools are agreed that he first devised the sled to transport objects and food too heavy for him to carry on his own back. Both assume too that he knew at a very early period how to convert sliding friction into rolling friction by placing round logs under his sled to facilitate its movement and that this suggested the wheel. From this point on the two schools differ. The older and larger one thinks along evolutionary lines and believes that by slow degrees the roller under the sled became a revolving axle with thin sections of larger logs or disks attached to its ends. Then followed the discovery that when a hole was made through the center of the disk so that it could revolve freely on the axle instead of the axle turning, the rudimentary form of the wheel of today was evolved. To reduce the weight of the solid disks man subsequently successfully tried thinner disks reinforced with crossbraces, and by the gradual elimination of excess wood and the addition of more crossbraces, the wheel composed of felloes and spokes resulted.

The second and newer school does not believe in the evolutionary development of the wheel but does believe that as soon as the value of the roller became known some individual proceeded directly to perfect a wheel by forming a circle of twisted reeds or grasses, which was kept in shape by crossbraces and prevented the wheel from col-

¹ Laufer, Berthold, Some fundamental ideas of Chinese culture. *Journ. Race Development*, vol. 5, no. 2, October 1914.

lapsing under weight. This "four-spoked wheel" was then attached to the ends of a revolving axle, and later a hole was drilled through the center of the crossbraces, thus permitting the axle to remain stationary and the wheel to revolve upon it. The oldest wooden wheel ever found, that of an Egyptian chariot, was composed essentially of a hub, spokes, and felloes just as in the modern wheel, and it is the contention of the newer school that such a wheel was a natural and logical development of a crossbraced circle of reeds and not of a section of a log. On the other hand, every bit of evidence pertaining to the history of early man indicates that his development was very slow and that he was mentally incapable of jumping in one leap the wide gulf between the roller and the wheel.

Regardless of the origin of the wheel, whether a section of logwood or a circle of reeds, the first wheels produced were certainly used to complete man's first wheeled vehicle, for he had no other use or need for the wheels. No description of it exists, but it was possibly a flat truck made of saplings tied together like a raft and mounted on 2 or 4 small wheels. This was used for heavy loads, and for lighter weights such as agricultural produce there was evolved a lighter 2-wheel cart. This is pure guesswork, of course, for one must jump a gap of 3,000 to 5,000 years to obtain the earliest real accounts of wheeled vehicles. They are Egyptian-made chariots of around 2000 B. C. to 1500 B. C. Of these earliest vehicles, Neuberger² writes:

The earliest form of wheel was probably a simple wooden disc of moderate thickness. The spoked wheel was also of wood originally and later was bound in metal; finally it was made entirely of bronze. Bronze wheels of this type that have been preserved have round spokes and a felly with a deep groove. The segments of the circular wooden felly were fastened together with rivets. The tire which bound together and served to fix the parts of the felly first rendered the wheel capable of surmounting the obstacles in its path. They were first made of nails, the heads of which were close together and covered the wooden fellies like scales. The tire was only later made of one piece and fastened only by a few nails. It was first made of bronze, later of iron. The body of the ancient Egyptian chariot rested directly on the axle, which was connected with the movable shaft. The round frame of the wheel consisted usually of six segments, which was certainly the easiest way of constructing it; for it was already known at that time that the radius of a circle can be stepped off six times around the circumference. Each segment was usually attached to the hub by a spoke.

The chariot for war and hunting purposes was so light in weight that one man could lift it; its wheels were about 2 feet in diameter, and it was always drawn by two horses. The Egyptians had in addition solid-wheel carts drawn by oxen for agricultural purposes and large, massive four-wheel trucks for funeral and religious purposes.

² Neuberger, Albert. *The technical arts and sciences of the ancients*. Translated from the German by Henry L. Brose. 1930.

Archeological records indicate that wheeled vehicles were adopted by the Assyrians almost simultaneously with the Egyptians, if not before, and that in subsequent centuries they gradually became an indispensable tool of all the civilized nations of the ancient world. Persia, Greece, and Italy in turn all made contributions to the vehicular art but especially to the improvement of the chariot, because that vehicle was of paramount importance both for hunting and for war. The Romans without a doubt were the largest contributors and after 300 B. C. had in general use the greatest variety of wheeled vehicles ever produced. This was due probably to the fact that the Roman rulers had instituted the construction of a network of permanent highways throughout Italy such as the Appian Way begun in 312 B. C., thus providing an incentive for vehicular improvements. Among the Roman vehicles were the chariot called the *biga* or the *currus* used not only for war and hunting but also for racing; a two-wheeled covered carriage known as the *carpentum* developed by the Romans as early as 500 B. C. and used by them for a thousand years; a light-weight two-wheeled gig called the *cisium* and used both for private and public rapid transit; a heavy four-wheeled freight and passenger wagon called the *clabulare*; a large four-wheeled coach for long journeys known as the *rheda*; and the humble two-wheeled farm cart called the *plaustrum*. There were, in addition, state and ceremonial wagons and carts, as well as litters, sedan chairs, and palanquins carried by slaves.

There is evidence, too, that the peoples of Europe were not slow in the adoption of wheeled vehicles once the wheel was made known to them. Most of the vehicles used in Italy during the time of Roman supremacy (27 B. C. to 467 A. D.) were of local origin, but there were some which were copies of vehicles found among their conquered foreign subjects. For example, the Roman two-wheeled cart, opened in front, closed behind and drawn by two horses, known as the *essedum*, was commonly used by the ancient Britons, Gauls, and Belgians. The Romans made it a vehicle for state occasions, by decorating it heavily with silver and gold overlays in beautiful designs. A less ornate *essedum* was also made for rapid travel and for hire along Roman roads. The Roman *harmamaza*, a four-wheeled, four-horse carriage for women and children was copied from a similar vehicle of Eastern origin, and the single-passenger traveling chariot closed at the back and sides but open at the front, known as the *covinus*, was modeled after the Belgian war chariot.

Little is known of the transportation media of the Middle Ages, but more than likely most travel was on horseback or in litters, and wheeled vehicles, except farm carts, were little used. During the Renaissance, however, the vehicular art shared in the general cul-

tural improvements of the period, and by the close of the seventeenth century there were in use not only elaborate chariots, coaches, and pleasure carriages of royalty and people of high rank, but also the privately owned coaches of wealthy citizens. Stage wagons as well as covered carts appeared on the highways. The eighteenth century saw the introduction of stage and mail coaches in Europe and the first practical attempts to improve the riding qualities of vehicles for the comfort of passengers. Carriages with the body cradled in leather straps had appeared in 1650, and in 1670 someone in England tried steel springs to ease road shocks. Neither idea, however, was generally adopted until well into the eighteenth century, and elliptical springs did not appear on vehicles until the beginning of the nineteenth century. This invention, made by Obadiah Elliott of Lambeth, England, in 1804, eliminated the long pole or perch of wood and iron connecting the front and rear axles of a vehicle and also the cross beds that had been regularly used. As Thrupp³ wrote:

By the introduction of elliptic springs the construction of wheeled vehicles has been rendered less costly, their weight has been materially reduced, and many complicated parts have been abandoned.

The invention really marks the beginning of the modern era of coachbuilding which, through the efforts of thousands of skillful coachmakers and wheelwrights throughout the world, brought the vehicular art to its highest attainments by the close of the century.

III

Archeological studies in the Western Hemisphere and in America indicate that man has occupied this portion of the world only since the close of the Pleistocene, for it was at this time that he is believed to have migrated from his native Asia. He was a savage nomad then and continued as such for a good many thousands of years, for he seems to have been somewhat backward. His relatives in Asia had almost passed through the Stone Age before he began it; in fact, age for age, he was just about 5,000 years behind the Egyptians and about 3,000 years behind the peoples of Europe. The oldest agricultural cultures in the United States in the Southwest are set at about 3000 B. C., and assuming that man's progress here ran a parallel course to that of his eastern relatives, it must have been about this time that he learned to domesticate animals. But in transportation, western man was greatly handicapped. True, he had the dog and llama, but he was without horses, the breed having become extinct thousands of years before his time. His progress in transportation was accordingly slow and continued so until the horse was brought to him by European immigrants following Columbus' discovery of the New World. Once

³ Thrupp, G. A., *The history of coaches*, 1877.

this contact was made and communication established with the Old World, transportation as well as every other human activity developed rapidly, so that by the time the modern age was well under way the great margin of cultural difference between the civilizations of the Eastern and Western Hemispheres had been reduced very materially.

When the time arrived in world history for the colonization of North America and particularly the United States, the people who undertook the task early in the seventeenth century met with difficult highway transport problems, for there were no roads—simply Indian footpaths and trails. Upon meeting this difficulty by widening paths and building rough roads, sleds, primitive two-wheeled carts, and three-wheeled wheelbarrows were put in service, the maintenance of which was the principal duty of the colonial wheelwright and blacksmith. Little time or labor was expended by them on vehicles for travel or pleasure, but nevertheless, before the close of the century the European coach had been imported and was used by a few wealthy citizens; the distinctly American chair had been evolved; and in New York America's first hack for hire had been started. With the rapid growth and territorial expansion of the Colonies during the eighteenth century, there developed real transport needs to augment the prevailing pack-horse trains for communication; for transporting farm products to market; for supplying the outposts beyond the Appalachians with food, clothing, and tools; and for bringing the outpost products back to the seaboard markets. This initial incentive was all that the American coachbuilders needed, and before the century ended several unique vehicles had been designed and put into general use, the most famous being the Conestoga wagon, named for its place of origin, the Conestoga Valley, Lancaster County, Pennsylvania.

Regarding the Conestoga, Omwake ⁴ wrote:

The probability is that the first Pennsylvania wagons were modified English covered wagons, suggested by those of the English settlers in Chester and Delaware Counties, the carters' or farm wagons of England, rather short and wide, dumpy—but strong and serviceable.

These wagons, however, did not fulfill all the requirements of the Conestoga Valley farmers, with the result that there came into existence about 1730 larger, heavier four-wheeled covered wagons, possessing many original features.

They differed from their English prototypes in that the Conestoga wagon bed was long and deep and was given considerable sag in the middle, both lengthwise and crosswise, so that should the load shift, it would settle toward the center and not press against the end gates; while the bed of the English wagon was flat and straight at the ends and its bows, holding the white cover, were vertical. The bows of the American wagon, however, followed the line of the

⁴ Omwake, John, *The Conestoga six-horse bell teams of eastern Pennsylvania*, 1930.

ends of the body, slanting outward and giving the distinctive and unmistakable silhouette of the Conestoga. Infinite variations occur, but always these characteristics remain.

The Conestoga was a ponderous vehicle capable of carrying a load of from 2 to 4 tons. In the larger ones the top ends of the body were as much as 16 feet apart; the top of the front bow supporting the white cover was 11 feet above the ground; the rear wheels were 5 to 6 feet in diameter; and the cover was 24 feet long. With a six-horse team pulling, the overall length of the wagon and team was about 60 feet. Although designed primarily for general use on the farm, Conestogas were soon adopted for overland freight haulage, and for upward of 100 years (1750-1850), the bulk of the goods and most immigrant passengers were transported to the West and back in these vehicles and their smaller cousins, the prairie schooners.

As the Colonies became more permanently organized, particularly in the New England and Middle Atlantic sections, and as settled communities and towns were established, there arose a real demand, political as well as commercial, for the betterment not only of the primitive and much traveled routes between places but also of the mode of conveyance of the traveler. Prior to 1700 the person who was compelled to travel from one town to another or one colony to another either walked or rode a horse. Later, besides these two, he had a third choice of riding among the barrels of flour and bundles of hides on a freight wagon. Then about 1725, stage wagons of English origin made their appearance here and there on the most traveled routes, and from that time on until the completion of a transcontinental railway in 1870, stage lines were the chief transportation agencies of the traveling public in the United States.

The stage coach at first was a simple, straight-sided, springless wagon with an oval woolen cloth top. Three or four wooden benches, without backs, placed crosswise served as seats for the passengers. "This is to give notice unto gentlemen, merchants, tradesmen, travelers and others" reads an advertisement in the Philadelphia Mercury of March 1732, "that Solomon Smith and James Moore of Burlington, N. J., keepeth two stage wagons intending to go from Burlington to Amboy, and back from Amboy to Burlington again, once every week or oftener if that business presents." The owners and operators of this line did not devote their stage exclusively to passengers and took what freight they could obtain, but the unique and great advantage to the traveler in the establishment of this line was that for the first time in the history of America on certain days of every week (weather permitting) there was available to him a way to get from Burlington to Amboy and back again.

Such regular schedules over the same route were quickly inaugurated in many other sections of the Colonies following this initial

venture, and as rapidly as the traveling public took advantage of it and patronized the stage companies, the latter returned the favor by improving the riding qualities of their wagons and by not including freight in the same payload with passengers. They also increased the distances between the termini of their runs, increased the number of scheduled runs a week and reduced the time of runs between points. Thus, in 1771, John Mercereau advertised that his "Flying Machines" would make during the summer months three scheduled trips a week each way between New York and Philadelphia in the remarkable time of 1½ days. He ends his advertisement in this fashion: "As the Proprietor has made such Improvements upon the Machines, one of which is in Imitation of a Coach, he hopes to Merit the Favour of the Publick." In his reckoning of a day and a half elapsed time between the two cities Mercereau apparently did not see fit to consider that a New York passenger bound for Philadelphia had to leave his home the night before a scheduled run, take a sail boat to Perth Amboy and get aboard the "Flying Machine" at 3 o'clock in the morning!

Despite these and other discomforts suffered by the paying passengers, public transportation agencies thrived, and by 1800 competing stage lines made scheduled runs between all of the principal cities and intervening towns in the East. It was possible, too, to get to the border of Indiana by stage wagon, although it required 2 weeks time riding 16 hours a day over the roughest kinds of roads and cost \$45 in stage fares plus \$20 for board and lodging en route. The wagons were very much improved, however. They were still without springs, but the body had been enlarged both in height and width; the oval top had been replaced by a flat-roofed one with leather or cloth side curtains; the benches had either wooden backs or strips of leather stretched across the wagon to serve as back rests; and, in rare instances, the seats were set on wrought-iron springs or swung in leather straps. The wagons were painted in bright red, gold, and blue, and were usually drawn by four horses.

After the first decade of the nineteenth century, the stage coach became a very permanent institution in American life and with it came the organization of a distinct coach and carriage making industry. Competition between lines was keen, and to secure and maintain patronage the companies sought coachmakers' and wheelwrights' help to design vehicles accommodated to the peculiar requirements of stage travel, with the result that there were soon on the highways stage coaches of a number of patterns. They were built in many places—at Salem and Worcester, Mass., Troy and Albany, N. Y. All were famous in their day, but in the 1820's came the still more famous Concord coach of Concord, N. H., the basic design of which was followed in the making of practically every stage coach con-

structed after that time and even of the first railway cars. By 1832 there were 106 lines of coaches running out of Boston alone and in 1864 one man operated 260 Concord type coaches in California. Of the Concord coach Banning⁵ wrote:

It was as tidy and graceful as a lady, as inspiring to the stage-faring man as a ship to a sailor, and had, incidentally, like the lady and the ship, scarcely a straight line in its body.

Specifically, the coaches weighed a ton or more and the body was suspended over the chassis on two sets of heavy leather straps, there being three or four layers of straps arranged one on top of the other like the leaves of an automobile spring. The straps were attached at their ends to 4 upright steel stanchions bolted to the axles, 1 near each of the 4 wheels. An outstanding feature was that both the driver's seat and the boot at the rear for baggage were all part of the body and not secured to the chassis as in earlier coaches. It had a powerful brake, too, operating on the rear wheels with a hand, and later foot, lever 5 to 7 feet long. Nine passengers could crowd into the coach, 3 on the back seat, 3 on the front seat riding backward and 3 on an extra seat between. The coaches were brilliantly painted and decorated with floral designs in red, gold, and yellow and were drawn by four and very often six horses.

While there were a few affluent citizens in each of the larger cities of the Colonies who owned their own vehicles (there was a total of 85 carriages in New York in 1770), the hard times following the struggle for independence tended to promote rigid economy with all the people, so that at the beginning of the nineteenth century private conveyances were rarely seen. As the country grew prosperous, however, there developed great popular demands for something to ride in, and especially for the two-wheeled chaise, that is, the "one hoss shay" immortalized by Oliver Wendell Holmes. It had been introduced from England long before the Revolution, and for generations thereafter no radical changes in design had been tolerated. According to DePew,⁶ chaises

had enormously high wheels, and the tops were stationary, being supported on iron posts. Curtains of painted canvas or leather covered the sides and back. These chaises were often built without dashers or aprons in the earlier times but in later years they had falling tops and were gay with silver plate. So universally was this the style of carriage in use that most carriage makers were known as chaise-makers. Chaise making thrived mightily and up to about 1840 it seemed that nothing could ever fully supplant the favorite old two-wheeler.

In the offing, however, there was a vehicle which some unknown American builder had designed and introduced about 1826 and which

⁵ Banning, Albert, Six horses.

⁶ DePew, Chauncey M., One hundred years of American commerce, vol. 2.

for 15 or more years had been struggling for existence and recognition. This was the buggy. Its name was not original, having come from an English two-wheeled light cart carrying one person. But the design throughout was purely American in origin and was with its subsequent improvements the greatest achievement of American carriage makers. Of the buggy, Thrupp⁷ wrote:

These American waggons were modelled from the old German waggon, but they have been so much improved as to be scarcely recognized. American ingenuity was lavished upon these waggons and they have arrived at a marvel of perfection in lightness. The perch, axletrees, and carriage timber have been reduced to thin sticks. The four wheels are made so slender as to resemble a spider's web. The bodies are of light work like what we call cabinet work. The weight of the whole waggon is so small that 1 man can lift it upon its wheels again if accidentally upset and 2 persons of ordinary strength can raise it easily from the ground. The whole is so slender and elastic that it "gives"—to use a trade term—and recovers itself at any obstacle.

When it was first introduced, the front wheels of the buggy were smaller than the rear ones, but later all four wheels were nearly of the same height with the body suspended centrally between them on elliptical springs. Being new and without any standard of shape to hamper the fancy of the builders, buggy bodies were made in a multitude of forms. During its 50 and more years of popularity there appeared the ribbed, the stanhope, the Jenny Lind, the coal box, and many others with varied names, but none of them retained the popularity accorded the so-called "square-box" buggy of which Stratton⁸ wrote:

Today, should we order a buggy for life use, a vehicle of this description would be selected, with the certainty that we should always have a *respectable* turnout for the road as long as it would last.

The common-sense construction of the buggy was wholly unlike the work of any other country, and its simplicity, lightness, sturdiness, and cheapness made it in time the most popular vehicle of the civilized world. As a matter of fact, it is reported that as early as 1869, certain English carriage makers advertised that they were prepared to build light carriages "on wheels imported from America." Throughout the nineteenth century and in spite of the introduction of a host of other vehicles such as the gig, phaeton, landeau, stanhope, clarence, rockaway, coupe, curricule, sociable, and victoria, the simple buggy maintained its lead in popularity and in all-around utility for passenger conveyance. Even as late as 1895, one writer on vehicles predicted that the buggy, because it was so admirable in all respects and inexpensive would not go out of use for "at least another century." But, even then the "horseless carriage" was

⁷ Thrupp, G. A., *History of coaches*. 1877.

⁸ Stratton, Ezra M., *The world on wheels*.

struggling to make itself heard above the loud praise of the buggy, just as the latter had attempted to shout down the old one-hoss shay 70 years before.

Looking backward over the thousands of years of development of highway travel, one sees an intimate relationship between the highway and the vehicle. First the trail suggested vehicles, then the vehicles suggested better trails. The improvement of trails into roads permitted the betterment of vehicles, and so the story is repeated century after century with constant improvements of each agency. In the United States between the seventeenth and twentieth centuries the gradual improvement in highways permitted the gradual improvement of vehicles from the heavy, massive, combrous, slow, springless cart and wagon to the light spring wagon and dainty speedy buggy. And of the host of vehicles devised in this time, none so clearly illustrate this transition and none were so intimately associated with our political, commercial, and cultural development as the Conestoga wagon, the stage coach, the chaise, and the buggy.

IV

Toward the close of the eighteenth century when so many interesting new applications of the mechanical sciences were being made in Europe, there developed a belief in some quarters that man could, by some mechanical contrivance, propel himself as readily as he could be drawn by a horse and wagon. His first efforts in this direction rather disproved the theory, for there resulted very cumbersome and complicated vehicles, the propulsion of which was most laborious. One of the first of these was a 4-wheeled chaiselike vehicle called a "Quadricycle" mentioned by a professor in Trinity College, Dublin, Ireland, and described in the *English Gentlemen's Magazine* for August 1769. The front wheels were steered by means of a handle coming up through the floor and the two back wheels, 5 feet in diameter, were driven by means of a pair of ratchet wheels on their axle. The published description continues thus:

The method of putting this chaise in motion is this: A person being seated in the body takes hold of the handle to direct it while another person gets into the box (over the rear axle) and treading alternately on the planks behind, turns the pulley, which makes the plates of iron catch hold of the notches in the little wheels and consequently sets them and the big wheels in motion, and forces the machine along, quicker or slower, according to the rapidity of the motion of the person's feet who stands on the planks.

A writer in the *London Magazine* of the same date in commenting on the Quadricycle wrote: "The velocity of these carriages depends upon the activity of the manager." Similar vehicles cropped up in subsequent years in France and Germany, but nothing came of any of them, for they were never publicly regarded as anything but a toy.

The idea of propelling oneself, however, remained, and in 1790 a Frenchman, de Sivrac, invented what he called a "Celerifere", which consisted of a wooden bar supported on two wheels, one before the other, and carrying a padded saddle. The machine was straddled and propelled by striking the feet on the ground (like the child's "kiddie kar" of today), but it could not be steered because both front and rear wheels were rigidly attached to the bar. In 1818 Charles, Baron von Drais, patented in France a great improvement on the "Celerifere" by mounting the front wheel in a fork socketed in the front end of the wooden bar thus making it possible to turn the wheel, steer the machine, and balance oneself when in motion. An added feature for comfort was a well-padded T-like support on which the rider rested his elbows. This machine, known as the "Draisine", is generally regarded as the "ancestor of the bicycle." It was introduced into England the same year of its invention, by a coachmaker, Denis Johnson, who took out a British patent for it, calling it a "Pedestrian Curricie", and for a time the contraption was quite popular for recreation, especially with young men, who gave it such names as "Hobby Horse" and "Dandy Horse" and who could speed along on the level at 10 miles an hour. The machine was patented in the United States in 1819 but failed to arouse much interest, and in England, to maintain interest, Johnson established a riding school, but even this could not offset the increasing public ridicule which soon brought about its demise.

For 20 years, more or less, little or nothing is heard of hobby horses, and then in 1839 or 1840 a Scotch blacksmith, Kirkpatrick Macmillan, made the first improvement in the development of the bicycle from the hobby horse by driving the rear wheel by cranks and swinging levers and steering the front wheel by direct sloping forks. The machine with its wooden frame and wheels with iron tires was a practical success and was extensively copied by local wheelwrights, but it did not enjoy much popularity. Macmillan should be remembered, however, as having anticipated by 40 years the rear-driving bicycle of today, although when pedals next appeared following his invention, they were fitted to the front wheels.

In Bar-le-Duc near Verdun, France, there stands a monument to the memory of Pierre Michaux, who is believed to have been the first person to suggest in 1861 or 1863 the fitting of cranks to the front wheels of an old "draisine." This claim is disputed by the champions of another Frenchman, Pierre Lallement, who, it is asserted, made the improvement about 1864 while working for Michaux, and becoming dissatisfied with the latter's treatment, emigrated to the United States, where on November 20, 1866, he received a patent for the idea. At all events Michaux and his son made and sold front-

wheel-drive bicycles, equipped with the latter's twisting handle-bar brake on the rear wheel, during the 1860's and exhibited machines at the Paris Exposition of 1867. One of these reached England the following year and was reproduced in quantity by the Coventry Sewing Machine Company. It proved immediately popular both in England and France, and by 1869 a host of manufacturers, some making Michaux and others Lallement models, were operating at capacity to meet the demand. A similar activity developed in the United States beginning in 1868 with Lallement's machine and with the patented improvements of the Hanlon brothers, consisting of a better frame, larger front wheel, and slotted cranks.

Thus was started the modern cycling era covering a period of some 30 years until the beginning of the twentieth century. Seemingly, almost every month during the first decade of this period, especially in England, some novel improvement in the bicycle appeared. Wire-spoked wheels were applied in 1869 by Reynolds and Mays; James Starley in 1870 produced the first all-metal machine, equipped with solid rubber tires and with a patented provision for tightening the spokes; and in 1872 J. K. Starley introduced his "spider-wheel" bicycle, one of the earliest of the "ordinary" bicycles—the type name applied thereafter to the high-front-wheel machine. Throughout the 1870's and into the 1880's the front wheel was gradually enlarged to obtain greater speed without increased pedaling speed to a maximum of 60 inches. Solid iron frames, too, were replaced by tubular ones of steel; ball bearings were introduced, and the weights of the machines were reduced from 60 or more pounds to 20 pounds. The "ordinary", however, was never admittedly a safe bicycle to ride, the rider running the risk of taking "headers", and as early as 1873 or 1874 H. J. Lawson, in England, made the first experimental rear-chain-driven safety bicycle. This was too drastic and sudden a change from the "ordinary", and instead the "Xtraordinary" was developed, with the rider's seat further back from the center of the big wheel; then the "kangaroo" and the "grasshopper", with the dwarfed front wheel, were introduced; and finally, in 1879, came Lawson's commercial model of his "safety", called the "bicyclette."

Meanwhile in the United States, after its first brief spurt, the interest in cycling had waned considerably, and only an occasional boy was to be seen trying out his father's old "boneshaker." In 1878, however, the Pope Manufacturing Co. in Hartford, Conn., was organized and began the manufacture of its high-wheeled "Columbia" bicycle along the lines of the best English-made "ordinary." It proved immediately popular, other bicycle makers entered the field, and in the course of the next 10 years cycling in the United States reached the proportion of a craze. In England during this

period, Starley and Sutton, Lawson, Singer, and Humber were quietly going ahead with the development of the low-wheeled, chain-driven bicycle. Then in 1885, Starley and Sutton invented and introduced the "Rover", which embodied most of the features of the present-day bicycle. This machine is generally recognized as the one which settled once and for all the superiority of the safety arrangement as over against the high-wheel type. Cyclists in America at first were rather loath to adopt it, but after 1890, following J. B. Dunlap's successful application of pneumatic tires to bicycle wheels which he patented in 1888-89, high-wheel machines rapidly disappeared. In subsequent years inventors in Europe and the United States added many refinements to the "safety", all of which enhanced the immense popularity which it enjoyed. By 1896 there were 4,000,000 riders in the United States and in 1898 the 250 bicycle manufacturers made and sold over 600,000 machines. Thereafter production and use declined in favor of the automobile, but in 1933 production had again climbed almost to the 1898 record.

Although the bicycle was and still is primarily a vehicle for recreation rather than for highway travel, it played a very important part in hastening the advent of the practically successful automobile. Not only was the bicycle manufactory the preparatory school of the automobile craftsman, but also many of the fundamental parts of the automobile were invented and developed by the cycle industry, including the differential and free-wheel clutch (for tricycles); the steering mechanism (for tandem bicycles); wire-spoked wheels; and adjustable ball-bearings and roller bearings. Again, it was due to Dunlap's untiring efforts to provide his son with an easier riding bicycle that the pneumatic tire was perfected. And lastly, it was due to the agitation of the formidable host of members of the League of American Wheelmen that brought about improved methods of mending old roads and the construction of many miles of good, new roads.

V

Considering regularity of operation, comfort, and speed, it may be said that the peak of development of public highway travel in horse-drawn vehicles was attained in Europe early in the nineteenth century. The regular and speedy transportation of the mails was of prime importance, and on the Royal Mail coach was heaped all the accumulated experience of coachmakers and wheelwrights to make that vehicle worthy of its hire. As a result, mail coaches with 4 to 6 passengers made daily and weekly runs with numerous changes of horses en route in the phenomenal time of 8 miles an hour.

Very shortly after the introduction of these fully developed coaches there appeared two entirely new kinds of vehicles, neither

one of which used brute power for its propulsion. One was the hobby horse and the other was the steam-engined coach. The people of Europe had been prepared more or less for the "horseless carriage", for there had already been made numerous applications of the power of steam not only to operate machinery and to pump water out of mines but also to propel boats. Nevertheless, man the world over had been accustomed too long to animal-drawn vehicles to accept the new contraption immediately, and his first impulse, in which he succeeded temporarily, was to ridicule it out of existence.

As early as 1769, the year in which James Watt patented his improved steam engine, Nicholas Cugnot, a French captain of artillery, constructed a three-wheeled steam tractor for pulling heavy cannon. It traveled at the rate of $2\frac{1}{4}$ miles an hour, but the steam generated in the boiler lasted only 12 to 15 minutes. Fifteen years later, William Murdock, one of Watt's workmen, made several successful experimental steam carriages of model size, but under pressure from his employer he soon abandoned the invention. Then came three bold individuals, Richard Trevithick in England and Oliver Evans and Nathan Read in the United States, the first two champions of high-pressure steam engines and all of them advocates of the use of such engines, because of their lightness and compactness, to propel road coaches and wagons. Trevithick actually built a steam road coach in 1803 and tried it in the streets of London, and Evans in 1804 transported through the streets of Philadelphia under its own power a steam dredge that he had built for the city. Read petitioned the Congress in 1790 for a patent on the application of his double-acting steam engine to road carriages, but that body so ridiculed the idea that he eliminated it in his second petition of 1791. The three men were, of course, considerably ahead of their times, and their respective efforts came to naught except that they paved the way for others to try their hands at steam highway travel.

After a lapse of some 20 years, W. H. James and Sir Goldsworthy Gurney in England and Thomas Blanchard in America revived the idea through the invention of their steam carriages in 1824 and 1825, respectively. Blanchard failed to obtain either moral or financial support, but Gurney did, and a coach was built in 1827 weighing 2 tons and, with 6 passengers inside and 12 outside, attained a speed of 15 miles an hour. Gurney's coaches were taken over by Sir Charles Dance, who improved them and for 5 months in 1831 ran them regularly 4 times a day between Gloucester and Cheltenham, a distance of 9 miles. Speed, including stops, averaged 11 miles an hour. The public put an abrupt halt to this venture, however, by continually

throwing obstructions in the road and by imposing road tolls, which in some instances, amounted to half the cost of operating the coaches. Undisturbed by this, Walter Hancock in England built 9 steam coaches between 1827 and 1838, and in 1832 started a regular steam omnibus service between London and Paddington. By 1833 there were as many as 20 steam buses traveling in and around London, and there seemed some hope that the steam automobile was to remain in spite of its noise and smoke. The "Road Locomotive Act", however, passed by the British Parliament in 1836 imposed such an enormous tax on these vehicles that it caused the immediate abandonment of all such enterprises. Although this was a bitter blow to the promoters of steam-coach service, they were, even then, aware of a growing diversion of their traffic to the new steam railways and no doubt realized that the latter would eventually bring about the closing down of their projects.

From 1836 to 1876 steam railways held the center of the stage, and the only interest manifested in self-propelled vehicles for highway travel was that shown by the occasional inventor in Europe and America who timidly demonstrated his improvements in steam carriages. Meanwhile two events occurred in the United States which in themselves had no bearing whatever on highway travel but which were of tremendous importance later in the development of the automobile.

Explorers following Christopher Columbus to America occasionally discovered, particularly in what is now western New York and Pennsylvania, small springs and pools of oil and in recording these discoveries went on to describe how the Indians used this oily, foul-smelling stuff for certain medicinal purposes. Subsequently the immigrant settlers in America began using this so-called seepage oil as the Indians did, and for generations thereafter it was considered by many as the panacea of all human ills. In 1850 in Pittsburgh, Pa., Samuel Kier, who had been bottling and selling through druggists "Kier's Rock Oil", had difficulty disposing in this way of all of the crude oil flowing from his salt wells at Tarentum and began experimenting with the oil as an illuminant. When burned it gave off an offensive odor and much smoke, and Kier, at the suggestion of a chemist, tried to refine the oil by distillation. He eventually succeeded in doing this on a commercial scale and thus became America's first oil refiner and showed the way to the production of gasoline. A few years after this, Edwin L. Drake drilled a well at Titusville, Pa., from which there began flowing on August 27, 1859, a thousand gallons of petroleum a day. This started the great oil industry in America.

The discovery and availability of these new liquid fuels rekindled an interest in steam-propelled vehicles, the pioneers in this instance

being Bollee and Serpollet of France, the latter becoming, toward the close of the century, one of the greatest steam automobile manufacturers in Europe. In America, interest lagged somewhat, and following the early efforts of Dudgeon, Reed, and Roper, few contributions were made until the last decade of the century, when Whitney patented his steam car in 1895 and sold the rights to the Stanley Brothers. The Stanley Steamers which they made and sold in the next few years, together with the low-price Locomobiles subsequently produced under their patents by Barber, played a very definite part in making America automobile conscious. But, hardly had the steamers obtained a foothold in the public regard when they were pushed aside for good and all as far as highway travel was concerned by the gasoline-engined automobile.

During the time that the exponents of the steam-engined carriages were devoting their attention to utilizing the heating qualities of the liquid fuels to raise steam for such vehicles, another group of inventors was working on the perfection of engines which could utilize the explosive properties of the fuels. The general idea was not new, for as early as 1794 an English inventor, Robert Street, had patented an explosive engine using gases distilled from turpentine, and in 1799 LeBon, in France, produced a similar engine using ordinary illuminating gas ignited by an electric spark. Sixty years later another Frenchman, J. J. E. Lenoir, made the first practical engine of this type and inaugurated a prosperous gas-engine industry in Europe. Then, in 1876, N. A. Otto, of Germany, patented and introduced the greatest improvement in the internal-combustion engine, that of compressing the gas before exploding it. This is the type of engine universally used in automobiles today.

The gas engines made during this 16-year period of development (1860-76) were bought and used for stationary power work, and apparently but little thought was given to applying them to self-propelled vehicles. Historians have been of the opinion, too, that it was not until after Otto invented the four-cycle engine and after gasoline became more plentiful that experimental work was undertaken looking toward the use of gasoline instead of illuminating gas in explosive engines. It has recently been brought to light in Austria, however, that as early as 1864 Siegfried Marcus, a pioneer electrical engineer and inventor of Vienna, devised a free piston, two-cycle internal-combustion engine using benzine for fuel, and that he first used the engine to propel a small wagon. Furthermore, in 1875 Marcus built a second automobile in which he and his friends made many trips in and about Vienna. The machine had a four-cycle gasoline engine and many other advantages of the modern car,

including magneto-electric ignition and vapor or liquid cooling, but none of its refinements. This car is now in the Technical Museum in Vienna.

Although the Marcus machine of 1864 is claimed to be the first known gasoline automobile, nothing further came of it. In 1883, however, Gottlieb Daimler, of Germany, invented the light, high-speed four-cycle gasoline engine, and 2 years later Carl Benz, of Germany, successfully applied such an engine to a light and practical three-wheeled vehicle. He patented it in 1886, and "its direct successors, many of which were made and sold between that date and 1900, did more, perhaps, than any others to demonstrate the possibilities of the motor car."⁹ At first Benz had difficulty finding a market for his new vehicles, but all this was changed after 1888, when he began exporting and selling them in England and France. Daimler followed Benz in the production of automobiles when he harnessed one of his engines to wheels in 1887 and later became the maker of the world-renowned Mercedes car. Others soon followed the lead of Benz and Daimler, including Napier, Lancaster, Royce, and Austin in England, and Peugeot, DeDion, Renault, Bollee, and Panhard and Levassor in France. Before yielding to others, Panhard and Levassor developed in 1895 the general arrangement of the automobile as it is today—the chassis separate from the body and secured to the axles by springs; the engine placed upright and in front under a hood; and the clutch and transmission back of the engine.

America was by no means asleep during this time. George B. Selden had filed his application in 1879 for a patent on a gasoline-engined automobile, but Charles E. Duryea and Ellwood Haynes actually built the first successful gasoline automobiles in this country in 1893 and 1894, respectively. The practical performance of these machines coupled with the importation and demonstration first of Benz and later of other foreign cars after 1893 made the automobile a definite reality to the people of the United States. They vigorously accepted the new vehicle for highway travel, and before the close of the century a number of automobile manufactories had been established, including the Olds, Winton, Packard, Riker, Duryea, and Haynes-Apperson, and over 3,000 cars had been put into use. Passenger vehicles were the principal product then, but in the first year of the twentieth century, the automobile in unusual looking clothes began to appear. New York City had its first automobile ambulance; a railroad motor bus was used for the first time, and gasoline-engined wagons were tried out for the distribution and collection of the mails.

⁹ Catalogue of the Collections in the Science Museum, South Kensington, London. England. Land Transport. I. Road Transport. 1926.

The development of the commercial truck followed, and by 1904 there were over 400 registered in service in the United States. Motor buses were next and are today, with trucks, an important adjunct to railway service. That the development and growth of the automobile is the outstanding achievement in transportation in modern times is indicated by the fact that in the world today there are over 33,000,000 in use, a 10,000-fold increase in a little over 30 years. Of this immense number of cars, America possesses three-fourths, including over 100,000 buses and more than 3,000,000 trucks.

The Conestoga wagon, the stage coach, the chaise, and the buggy are now rare museum pieces. Each one in turn played an important part in the development of highway travel, and each in its time was believed to be irreplaceable. Their active lives stretched over a period of from 75 to 100 years. Today, the automobile is considered indispensable, but it is still a youngster, only 35 years old. Will it, too, be discarded 60 years hence for something else?

SELECTED BIBLIOGRAPHY

PRIMITIVE MAN

BISHOP, C. W.; ABBOT, C. G.; HRDLÍČKA, A.

1930. Man from the farthest past. Smithsonian Scientific Series, vol. 7.

HOUGH, WALTER.

1934. The domestication of animals. Sci. Monthly, vol. 39.

KROEBER, A. L.

1928. Anthropology. Harcourt, Brace & Co., New York.

NEUBERGER, ALBERT.

1930. The technical arts and sciences of the ancients. Trans. by Henry L. Brose, Macmillan, New York.

WISSLER, CLARK.

1923. Man and culture. Thos. Y. Crowell Co., New York.

HIGHWAY TRANSPORT

BARTLEET, H. W.

1931. Bartleet's bicycle book. Ed. J. Burrow & Co., Ltd., London.

BELLOC, HILAIRE.

1926. The highway and its vehicles. The Studio, Ltd., London.

DUNBAR, SEYMOUR.

1915. A history of travel in America, 4 vols. The Bobs-Merrill Co., Indianapolis.

FORWARD, E. A.

1926. Catalogue of the collections in the Science Museum, Land transport. I, Road transport. His Majesty's Stationery Office, London.

KAEMPFERT, W.

1924. A popular history of American invention, 2 vols. Charles Scribner's Sons, New York.

KIRKMAN, M. M.

1895. Primitive carriers. The World Railway Publishing Co., Chicago.

MITMAN, C. W.

1930. The beginning of the mechanical transport era in America. Ann. Rep. Smithsonian Institution, 1929.

OMWAKE, JOHN.

1930. The Conestoga six-horse bell teams. Privately published.

PRATT, CHAS. E.

1880. The American bicycler. Privately published.

STRATTON, EZRA M.

1878. The world on wheels. Privately published.

THRUPP, G. A.

1877. The history of coaches. Kerby and Edean, London.

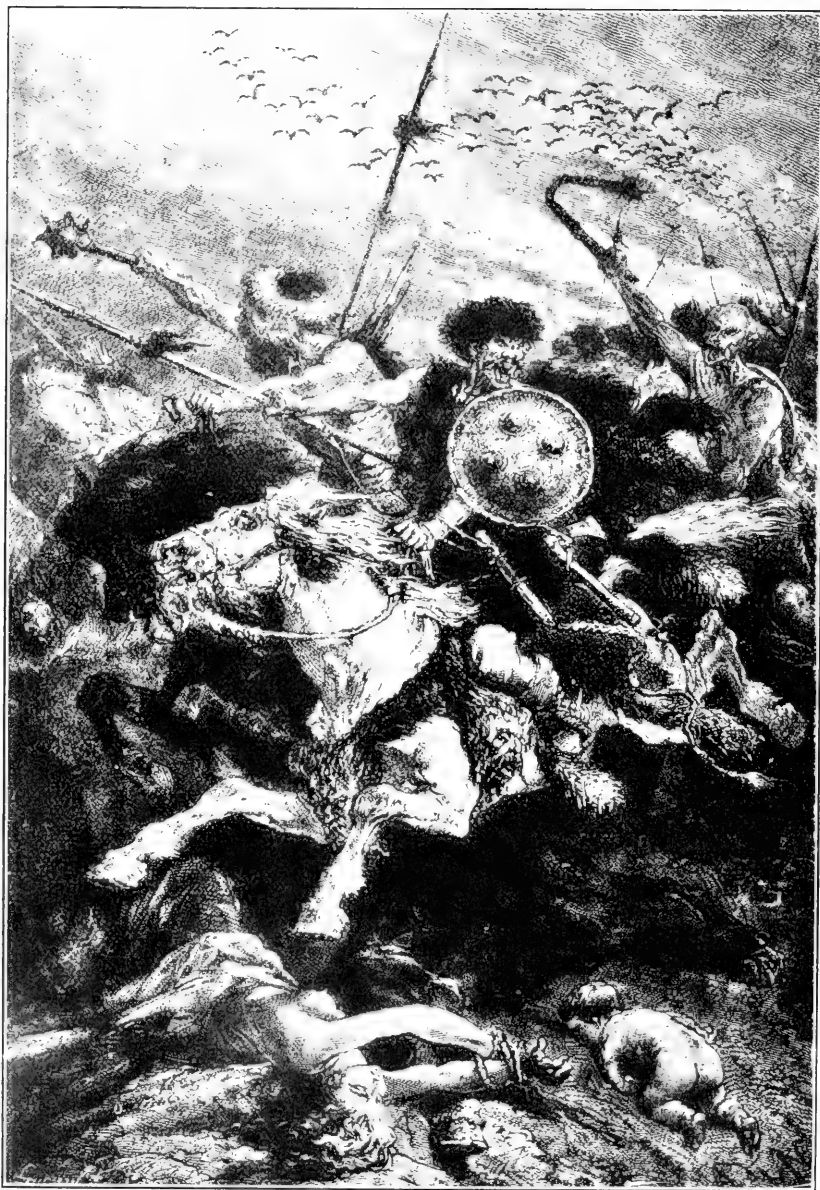
WILE, FREDERIC W.

1928. A century of industrial progress. Doubleday, Doran & Co., New York.



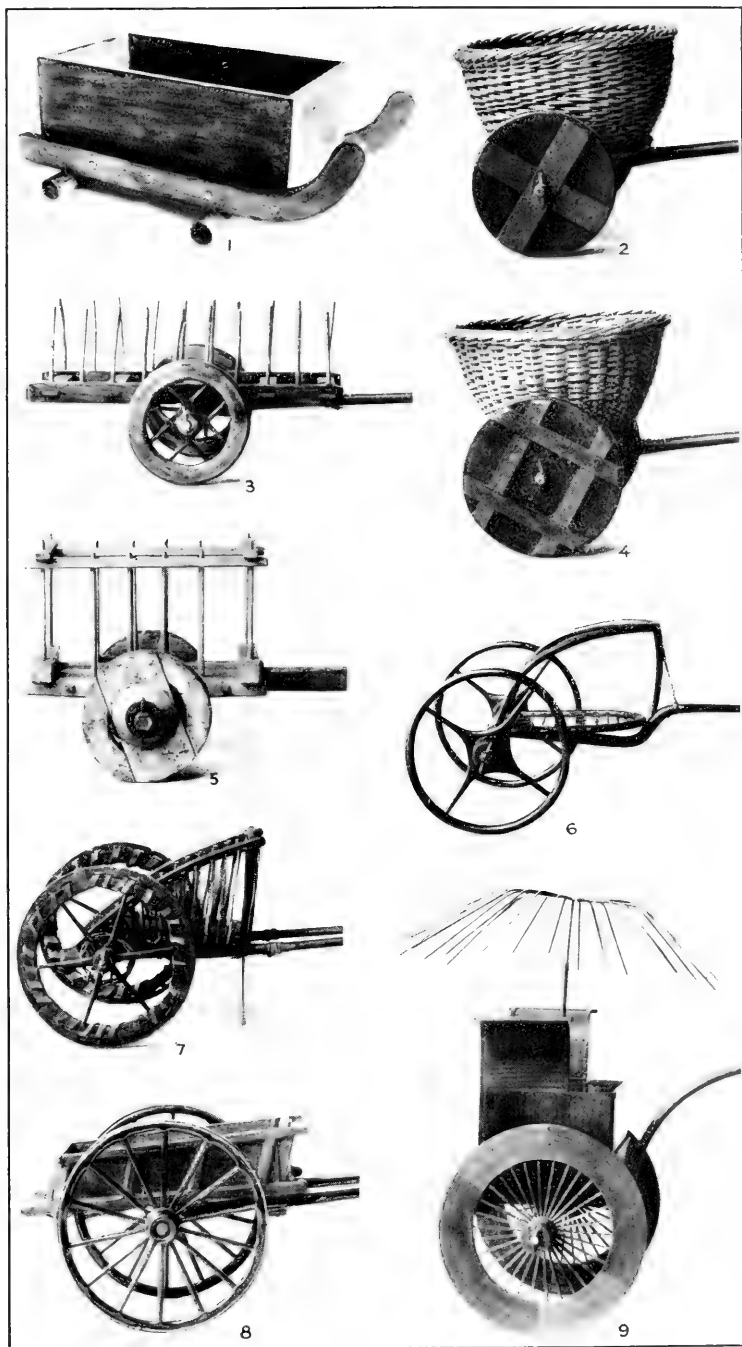
Courtesy the Field Museum of Natural History.

A NEANDERTHAL FAMILY—THE ORIGINAL CAVE MAN.



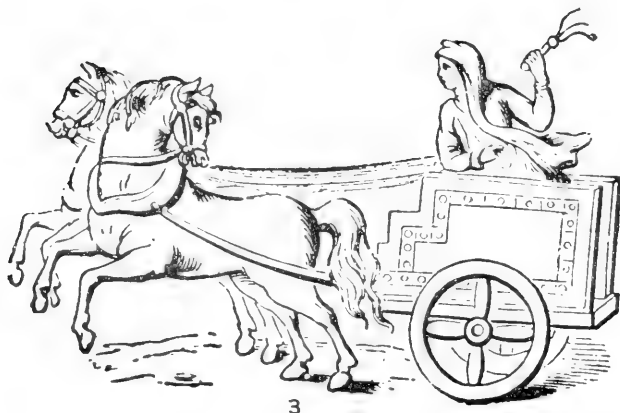
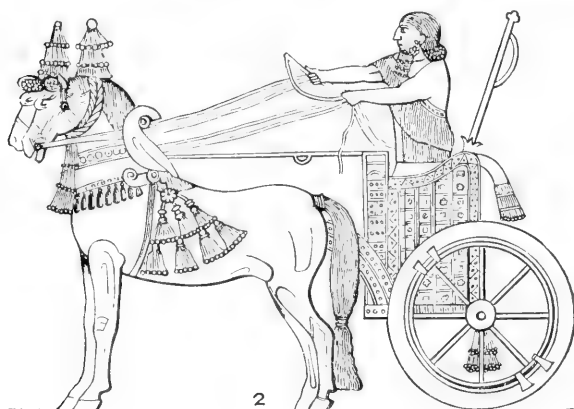
After a drawing by Albert de Neuville.

THE INVASION OF THE HUNS.



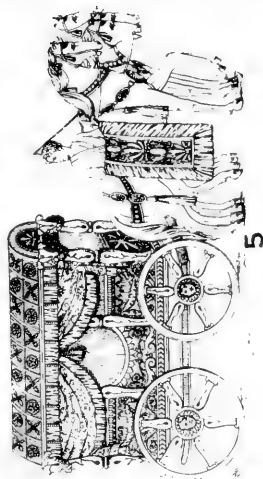
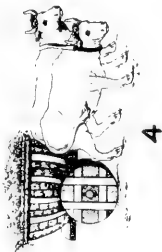
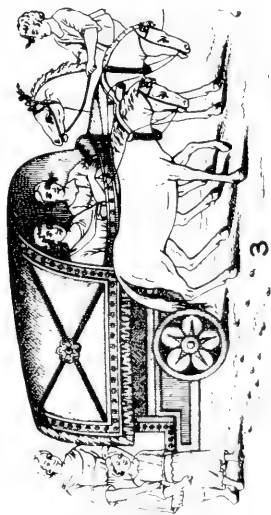
DEVELOPMENT OF THE WHEEL.

1, Egyptian sled on rollers; 2, Roman oil cart; 3, East Indian cart; 4, Roman farm cart; 5, Mexican cart; 6, Egyptian chariot; 7, Egyptian chariot; 8, modern farm cart; 9, Chinese chariot.



ANCIENT CHARIOTS.

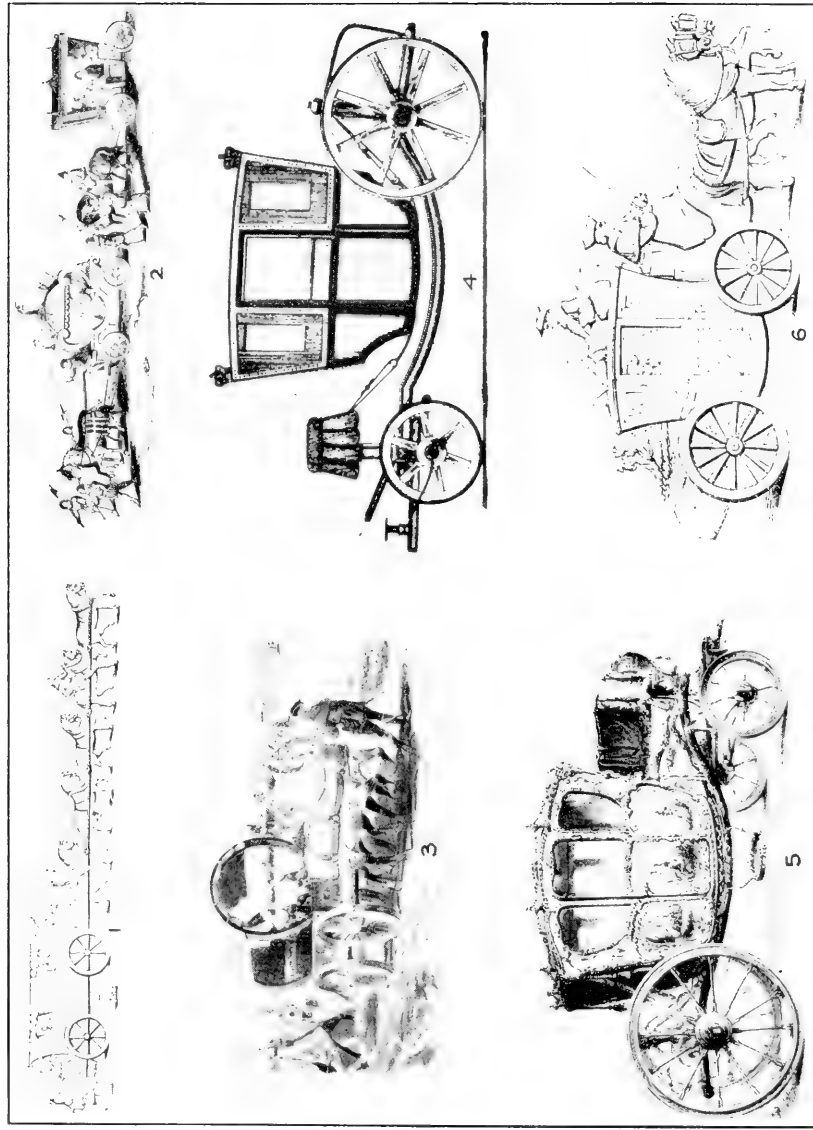
1, Egyptian; 2, Assyrian; 3, Saxon.



From Ginzrot, J. C. Die Wagen und Fahrwerke der Griechen und Römer und anderer alte Völker

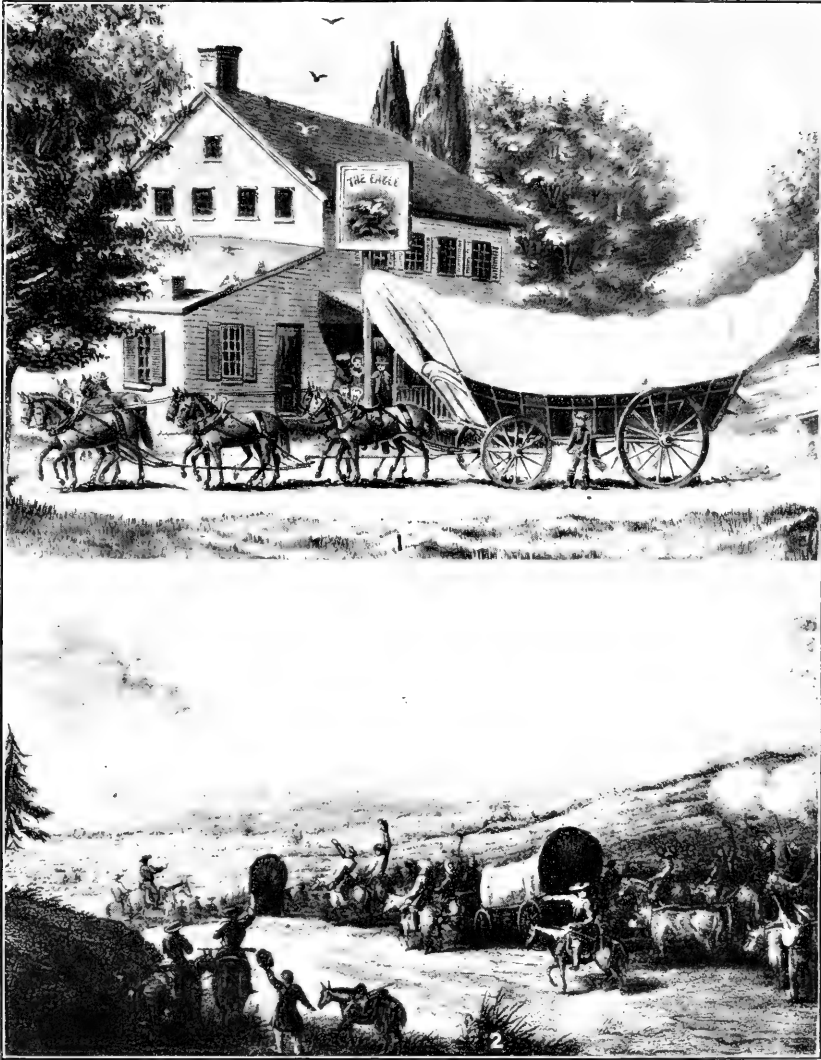
ROMAN VEHICLES.

1, Rueda; 2, racing chariot; 3, carpentum; 4, plaustrum; 5, harnamaya.

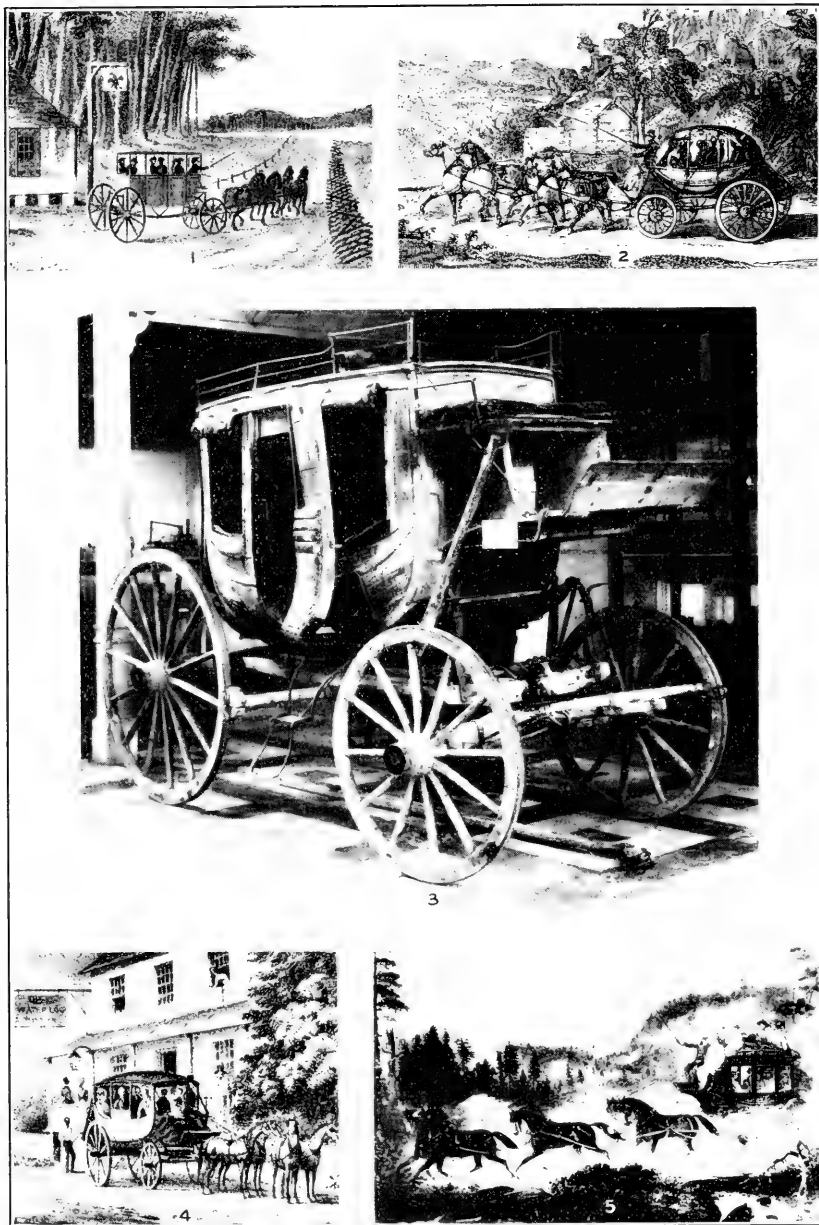


EUROPEAN VEHICLES, 14TH TO 18TH CENTURIES.

1, Whirligote, 1350; 2, Queen Elizabeth's coaches, 1450; 3, traveling coach, 1600; 4, gentlemen's coach, 1725; 5, state carriage, 1750; 6, stagecoach, 1750.

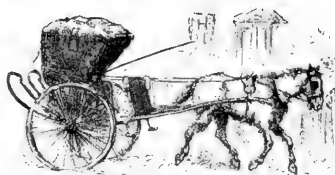
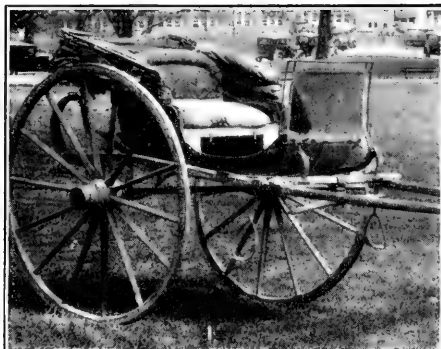


1, THE CONESTOGA WAGON; 2, THE PRAIRIE SCHOONER.



AMERICAN STAGECOACHES.

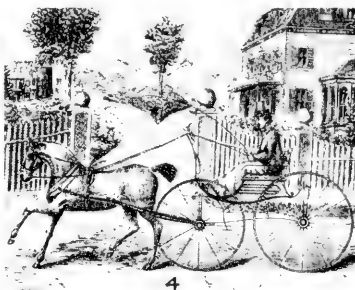
1, New England, 1795; 2, Midwest, 1825; 3, Old Concord (in the National Museum); 4, Baltimore-Washington, 1830; 5, Californian Concord, 1860.



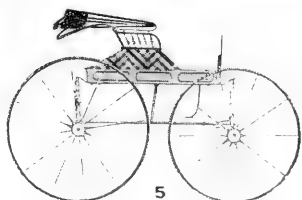
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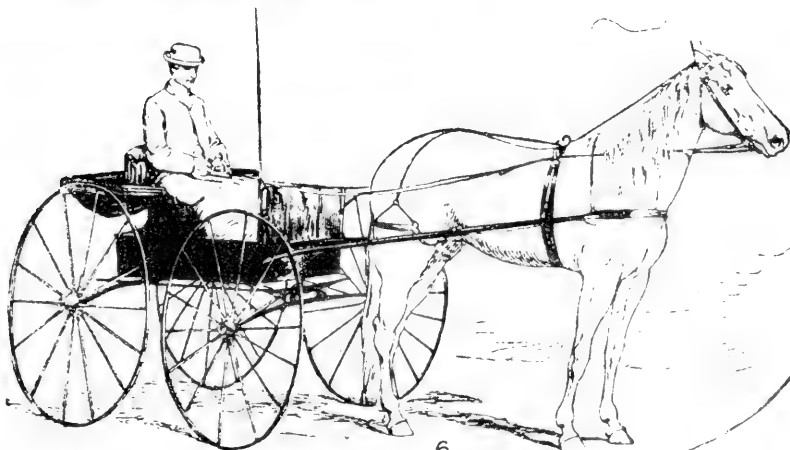
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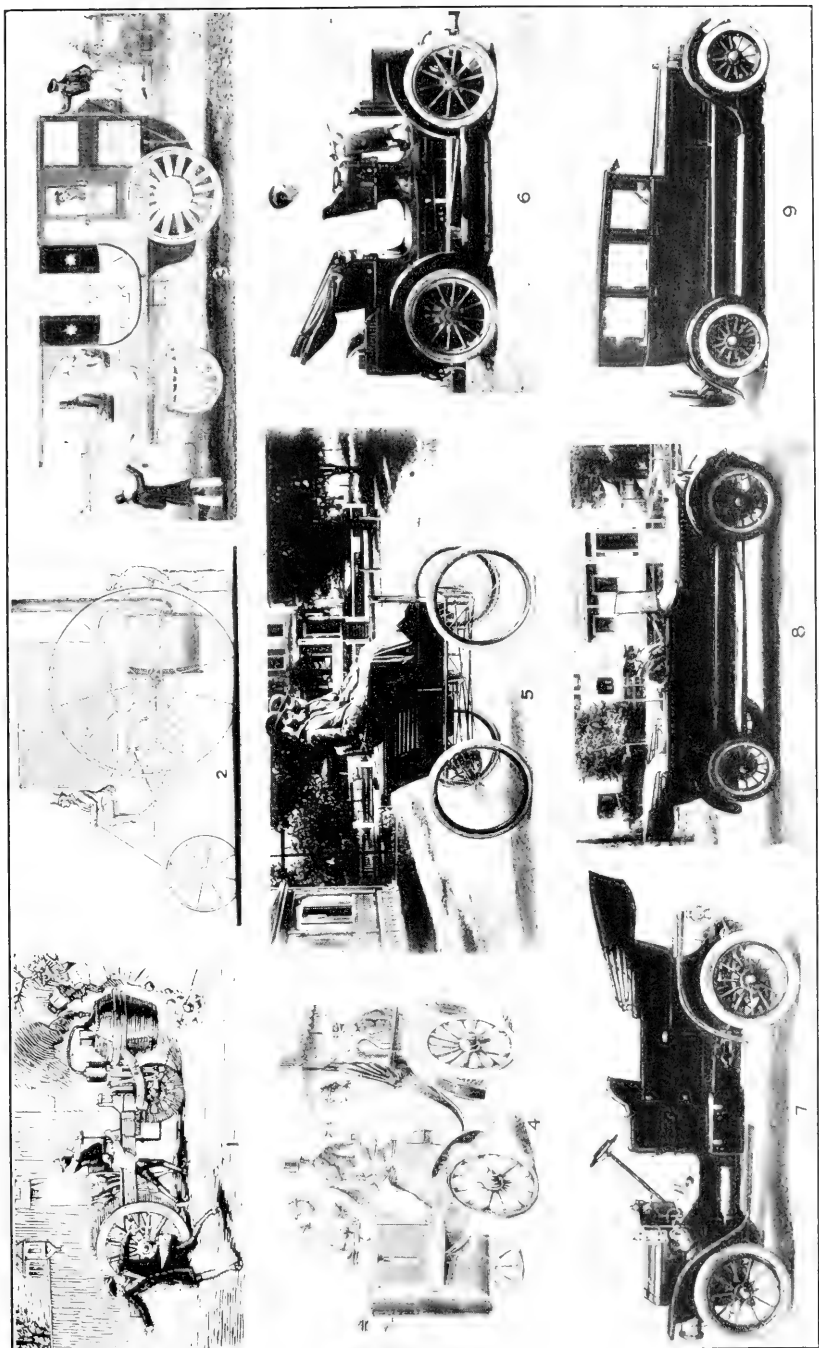
CHAISES AND BUGGIES.

1, Chaise or gig, 1797 (in the National Museum); 2, "The Wonderful One-Hoss Shay"; 3, chaise, 1830 (in the National Museum); 4, buggy, 1826 invention; 5, square-box buggy, 1810, one of the many styles; 6, buggy, 1900.



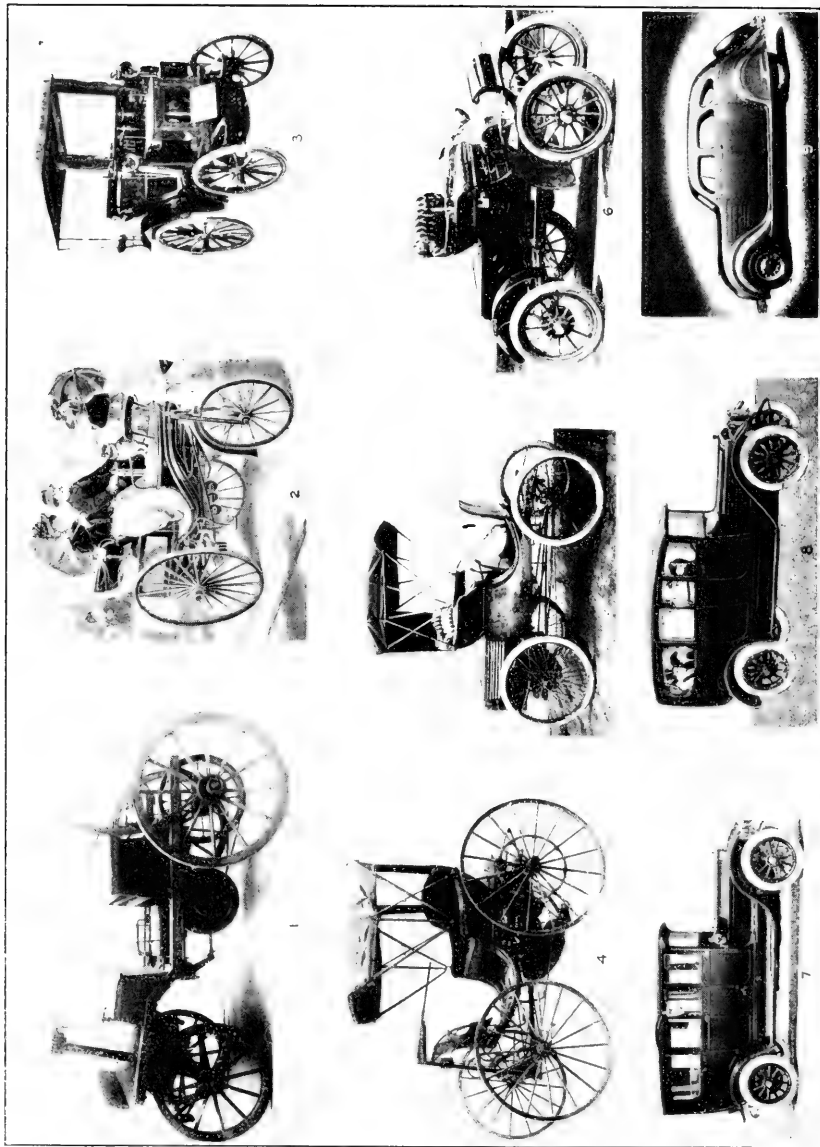
BICYCLES.

1, Draisine or hobby horse, 1818; 2, Lallement velocipede, 1869; 3, J. K. Starley "Ariel", 1873; 4, Columbia "Ordinary", 1885; 5, Humber racing "Ordinary", 1885; 6, American "Star", 1885; 7, Lady's "Victoria" 1887; 8, Starley and Sutton "Rover" 1885; 9, Snyder "De Luxe", 1928.



STEAM AUTOMOBILES.

1, Cugnot, 1769 (courtesy "Sturtebaker Wheel"); 2, Trevithick, 1803; 3, Hancock, 1835; 4, Bollee, 1878; 5, Stanley Twins, 1897; 6, Gardner-Serpollet, 1902; 7, White, 1910; 8, Stanley Twins, 1918; 9, American, 1924.



GASOLINE AUTOMOBILES.

1, Marcus, Austria, 1875; 2, Benz, Germany, 1888; 3, Panhard, France, 1896; 4, Duryea, 1893-1894; 5, Winton, 1898 (twenty-four sold for \$1,000 each); 6, Oldsmobile, 1903; 7, Pierce Arrow, 1912; 8, Winton, 1915; 9, Chrysler, 1934.

VIA APPIA IN THE DAYS WHEN ALL ROADS LED TO ROME

By ALBERT C. ROSE

Senior Highway Engineer, Bureau of Public Roads, United States Department
of Agriculture

[With 4 plates]

*"Trans gentile fretum placidi facundia Polli
detulit et nitidae juvenilis gratia Pollae,
flectere iam cupidum gressus, qua limite noto
Appia longarum teritur regina viarum."*

Such was the tribute paid by Publius Papinius Statius (A. D. 40-96?), the preeminent poet of the silver age, to the most famous highway since the dawn of historic time. From this poetic passage of Statius, whose style is sometimes artificial and his meaning hard to grasp, Slater (1)¹ has rendered the following translation which seems faithful to the original as well as pleasing in its idiom: "The honey-sweet tongue of gentle Pollius and the girlish grace of winsome Polla lured me to cross the bay of my native Parthenope, though fain ere then to be bending my steps where the beaten highway, Appia, queen of far-stretching roads, sweeps along its well-known track."

If the great poet, whose writings were revered by Dante, Chaucer, and Pope, had any other reason than custom for personifying the Appian Way as a queen, rather than a king of roads, it is not difficult to supply an explanation. A logical answer is that this great mother highway nurtured the commerce that sustained the power of the mighty Roman Empire, while at the same time the graceful sweep of this road over hill and valley made it a ruler, without a peer, among all the highways of the ancient world.

Roads built in other ages and in different climes will never be rivals for first honors with the Appian Way, if they lack the background essential for making their names echo down through the centuries. In North America, the Columbia River Highway (2) has become famous because it represents an example of superb engineering through a gigantic natural gorge which a mighty river has worn through the Cascade Mountains in the Pacific Northwest. Fur-

¹ Numbers in parentheses refer to the list of literature cited at the end of this paper.

thermore, the four-lane superhighway which connects Washington, the capital city of the United States, with Mount Vernon, the home of George Washington, will grow famous because it leads to a national shrine which is a Mecca for tourists and sightseers from every nation. Who would venture an opinion, however, that these roads shall ever vie for fame with the *Via Appia*?

Historical events and characters, rather than engineering quality, determine the place in the sun of a road, and the *Via Appia* was the most important road in the greatest empire the world has ever known. Julius Caesar rode in royal splendor over its flintlike surface, as reigning monarch of an earthly empire in a few centuries to pass into oblivion; whereas the apostle Paul, white-haired but resolute, wearily trod its surface on his way to Rome, where he proclaimed the foundation of a spiritual Kingdom which would never perish from the hearts of mankind (3).

ROME THE HUB CITY OF THE IMPERIAL ROAD SYSTEM

Rome became the hub from which roads were to radiate in all directions. From the legendary date of 753 B. C., when Romulus, its mythological founder, is said to have laid out the city foursquare under the name of *Roma Quadrata*, the boundaries were gradually extended until, as mistress of the known earth, the city occupied the area covered by the historic seven hills, adjacent to the Tiber River. During the period of the kings, which lasted until 509 B. C., there were no paved roads in Rome, and in fact the earliest pavement that has been found was laid in 174 B. C., on a street that ascends the Capitoline Hill. The period of the Republic, however, from 509 to 28 B. C., was marked by the extension of the jurisdiction of Rome over the peninsula of Italy, Carthage in Africa, and Asia, and roads were built vigorously in order to consolidate these victories. The roads provided means of communication for powerful military legions and swift messengers of the government and made possible commercial intercourse with the subjugated provinces.

MILEAGE OF ROADS IN THE MAIN ROAD SYSTEM

The system of main roads, shown in figure 1, called military, consular, or praetorian, depending upon their purpose or their builder, grew in magnitude until during the Empire, from 28 B. C. to its fall in the West in A. D. 476, it embraced, according to the Itinerary of Antonine, 372 main roads with a total length of 53,658 Roman miles.² These roads were distributed as to locality (4) as follows:

² The journey unit adopted by the Romans was the *milliarium*, of 1,000 paces of 5 feet, which equaled 1,481.47 meters or 4,859 English feet. In Gaul they measured by the Gallic league of 1,500 paces, or 7,289 English feet. The Roman foot (*pied*) was equal to 0.29556 meters, or 0.9694 of an English foot.

	Roman miles		Roman miles
Italy -----	13, 024	Corsica -----	125
Gaul -----	9, 320	Africa (less Egypt) -----	9, 348
Spain -----	7, 700	Egypt -----	1, 500
Great Britain -----	2, 579	Asia -----	8, 500
Sicily -----	1, 362		
Sardinia -----	200	Total -----	53, 658

The foregoing mileage includes only public ways (*viae militares*) leading from Rome to the provinces and large cities. In addition to these main roads there was a large mileage of parish roads (*viae vicinales*), connecting the public ways with the secondary

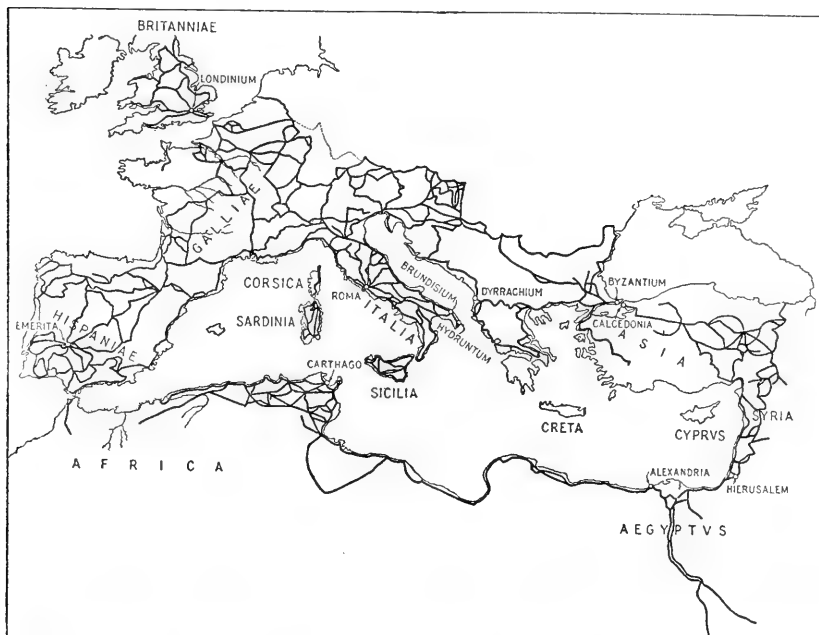


FIGURE 1.—Main road system of the Roman Empire as shown by the Itinerary of Antonine (A. D. 150) and the Itinerary to Jerusalem (A. D. 333), from Parthey and Pinder (16).

towns and boroughs, and of farm roads (*viae agrariae*) which made the public ways and parish roads accessible to the farms and hamlets. There was also a considerable mileage of mule paths (*itineres*).

VIA APPIA ONE OF THE 29 GREAT MILITARY ROADS

There were 29 great military roads radiating from Rome and extending to the extreme limits of the far-flung empire. Among these were the *Via Appia*, *Via Aurelia*, *Via Claudia*, *Via Flaminia*, *Via Salaria*, *Via Valeria*, *Via Praenestina*, *Via Labicana*, and the *Via Latina*. The great extent of these roads, their durability, and the ingenuity and audacity of the builders has been a source of admiration and astonishment in every age. Mountains, marshes, lakes, rivers,

and seas seemed to inspire rather than to dismay or to weaken the will to conquer of the indomitable Romans. Their audacity beggars description (5). They seem to have had little regard for topography and built in straight lines undaunted by natural obstacles. Mountains were cut through at tremendous expense, valleys filled, and marshes bridged. Even the seas did not halt their progress, for the roads were built up to the waters' edge and then continued upon the opposite shore. Thus the road in France from Rheims to the Channel was brought to an end temporarily by the intervening expanse of water, only to be resumed again in Great Britain, upon the other side of the Channel, whence it extended into Scotland. Similarly, from the southern extremity of the Appian Way at Hydruntum the sea was crossed to Dyrrachium, the western terminus of the great Egnatian Highway running through Macedonia to Byzantium.

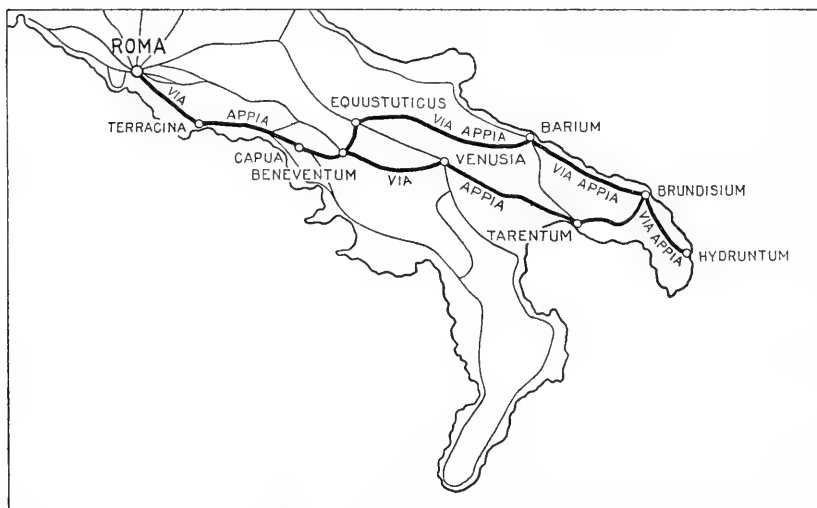


FIGURE 2.—*Via Appia* was a single road from Rome to Beneventum and from Brundisium to Hydruntum. There were two branches between Beneventum and Brundisium.

VIA APPIA THE MOST IMPORTANT ROMAN ROAD

The *Via Appia* was the most important of all the Roman roads and the first to be paved. It was the great south road (fig. 2) connecting Rome through Capua and Beneventum with Brundisium and its seaport Hydruntum, in southeastern Italy on the Adriatic Sea. The *Via Appia* began at the *Porta Capena* of the inner Servian Wall of Rome, built in the reign of King Servius Tullius (578–534 B. C.), and led through the *Porta Appia* in the outer Aurelian Wall. The distance from the *Porta Capena* to Capua was 132 English miles and to Beneventum 164 English miles. At Beneventum the *Via Appia* divided into two routes as far as Brundisium, thence it extended as

a single route to Hydruntum in southern Italy. The longest, the carriage route, covered 235 English miles and extended through Venusia and Tarentum. The shorter route, a bridle road, adapted to mule traffic, although Horace drove along part of it, passed through Equustuticus. Its length from Beneventum to Hydruntum was 216 English miles. Thus, the total length of the *Via Appia*, from the *Porta Capena* at Rome to Hydruntum on the Adriatic Sea was 412 English miles by the long route and 380 English miles by the short route (6).

The *Via Appia* was the most important of all the Roman roads because it led toward the fabulously wealthy regions of the East, in the direction of which there extended three main routes (7), from the harbor of Hydruntum, by:

1. Circumnavigating the Peloponnessus, or Grecian peninsula, and sailing directly for the Eastern ports by way of the Mediterranean Sea.

2. Boat to Lechaeon, the western harbor of Corinth, thence crossing the isthmus to the eastern harbor of Corinth at Cenchreae, and reembarking for places farther east.

3. Ship to Dyrrachium on the opposite coast of the Adriatic Sea and thence overland on the great Egnatian Road, through Macedonia and Thrace, to Byzantium. From Calcedonia, on the opposite shore from Byzantium, the road extended through Asia Minor, Syria, and Palestine across the Isthmus of Suez, through Egypt into Ethiopia in Africa, where the Romans are said to have gained their knowledge of paved roads from the Carthaginians.

ROADS WERE PREEMINENT AMONG ROMAN PUBLIC WORKS

The public roads ranked preeminent among the works of Roman magnificence. Untold amounts of wealth and labor were spent in their construction and only officials of the highest rank were considered worthy to be entrusted with the direction of the work on the important roads radiating from the heart of the Republic, or Empire, at Rome. During the Republic, the greatest men were made responsible for these highways, and during the Empire, Augustus himself assumed charge of the roads. Thus the roads, bridges, and other public works assumed quasi-religious significance because the Oriental subjects in the Roman population considered them as works of a semidivine ruler or his agents. As a result of this Caesar worship, there arose also in Italy shrines not to Augustus Caesar but to the "genius" of Augustus. It should be added, however, that except for the Orientals in the Empire of the West, this worship remained to the end only a lip service.

VIA APPIA NAMED AFTER ITS BUILDER, APPIUS CLAUDIUS

The construction of the *Via Appia* was initiated by Appius Claudius, Caecus (the blind), a famous general in the Roman army, as well as an orator and poet, who at the time occupied the position of Censor under the Republic. The duties of the Censor, who was one of the two ruling magistrates of the city, was to make a register of the number and property of the citizens, and to exercise the office of inspector of morals and conduct. Because of the fame of Appius Claudius, gained in large enterprises, and the fact that he was considered the originator of the work, the road was named *Via Appia* in his honor. The construction of this highway rendered immortal the name of Appius Claudius, and it is fitting that it should, for the road represents the consummation of an audacious plan. Its importance in history may be measured by the fact that it placed Rome in communication with southern Italy, Sicily, Africa, and Asia. Its construction required an immense amount of labor, because no expense was spared to make it beautiful as well as substantial. This gigantic enterprise required not months but years to complete, and thousands of slaves, freedmen, and soldiers, divided into brigades, worked under the direction of experienced architects and expert overseers.

CONSTRUCTION BEGAN ON THE VIA APPIA IN 312 B. C.

Appius Claudius ordered the road laid out in 312 B. C., at a time when the Romans were waging war against the Samnites. On those portions of the road where public funds were insufficient or lacking, Appius Claudius defrayed the expense from his own private fortune. He built the road no farther than Capua, because the provinces beyond were not under the dominion of the Romans at that time. The original *Via Appia* is thought to have been surfaced with gravel (*glarea strata*). In 298 B. C. the first mile, from the *Porta Capena* to the Temple of Mars, was paved with hewn stone (*peperino*) as a way (*semita*) for walking and riding on horseback. Later, 295 B. C., the entire road from the Temple of Mars to Boville was paved with lava (*silex*). About 280 B. C., it was extended to Beneventum, and then continued through Venusia and Tarentum to Brundisium, reaching the latter place by 244 B. C. The first mile, from the *Porta Capena* to the Temple of Mars, was repaved with lava (*silex*) about 191 B. C.

CHARACTER OF THE TRAFFIC ON THE ROMAN ROADS

For a long period of time the great roads between Rome and the provinces were only of strategic and political importance. They

were built to maintain communication between Rome and the military legions in order to expedite the transportation of reinforcements and supplies. The stores and *impedimenta* carried by each legion were considerable. Besides horses and pack mules, they included 10 great machines (*onagri* or *catapultae*), representing the heavy artillery of the times, and 55 small machines mounted upon chariots (*carroballistae*), for throwing stones and arrows. Only good roads were adequate for the rapid transportation of these engines of war and siege.

After the conquest of the neighboring provinces, the great roads provided for the prompt dispatch of military legions to localities menaced by uprisings and so assured the immediate suppression of any revolutionary undertaking. The ways also facilitated the return of plunder and taxes, which, when paid in silver or in kind, required a fast and safe means of transport. In addition, the roads permitted the rapid transit of news and despatches between the seat of government and the provinces. Lastly, the roads were conducive to peace because they diffused the benefits of Roman civilization by connecting the provinces and the colonies to the city. The commercial relations made possible by these roads welded the Empire together more closely than would have been possible by severity or force.

PUBLIC TRANSPORT DIVIDED INTO A FREIGHT AND A PASSENGER SERVICE

Thus with the consolidation of the Empire, the traffic upon the public roads (*cursus publici*) grew to such proportions that Diocletian (A. D. 284–305), by means of a rescript, found it necessary to divide the public transport into two classes: (1) the express service (*cursus rapidi*), and (2) the freight service (*angariae*).

ROADSIDE STOPPING PLACES ESTABLISHED BY GOVERNMENT

To facilitate the use of the great roads, there were distributed at more or less regular distances, depending upon local conditions, three kinds of establishments:

1. Relays (*mutationes*), from 6 to 13 miles apart.
2. Mansions (*mansiones*), lodging places for the end of a day's journey, from 28 to 37 miles apart.
3. Stations (*stationes*, *stativae*, or *civitates*), which were towns, or stopping places, for longer rest periods.

ADMINISTRATION OF THE EXPRESS SERVICE

The express service was under the supervision of officers called *praecepti vehiculorum*, who were generally freedmen of the emperor.

The personnel (*familia*) of the relays consisted of a chief (*manceps*), a kind of postmaster, and of freedmen performing the services of clerks, grooms (*stratores*—one for 3 horses), mounted couriers, postilions or chariot messengers (*veredarii*), farriers, veterinarians, etc. As a rule, 20 post horses (*veredi*) were kept at the relay stations, 40 at the mansions, and a still larger number at the stations.

LEGAL LOAD RESTRICTIONS UPON VEHICLES

Permissible loads for vehicles, such as travelers, baggage, silver, munitions, etc., were strictly limited and regulated according to the strength of the draught animals. In this connection a law of Constantine provided that *birotae*—carriages with two wheels—should be drawn by 1, 2, or 3 horses or mules, and the load limited to 144 English pounds (4); *rhedae*, should be drawn by 8 horses in summer and 10 in winter and carry a load not exceeding 718 English pounds; while *carri*, drawn by the same number of horses as the *rhedae*, were not permitted to carry more than 431 English pounds.³ These extremely narrow limits applied, however, only to fast vehicles. Even when loads were quadrupled for slow freight transportation, the weight would be equivalent to a maximum wheel load of 718 English pounds,⁴ assuming equal distribution of the load upon the four wheels. This load is less than half of the 2,000-pound wheel load, which Telford in 1819 (8) recommended as the limit for freight wagons in England, and it is only a small fraction of the 4,500-pound motor-truck wheel load permitted upon modern highways in the United States. Furthermore, the *rheda*, which provided a service similar to the French stagecoach of the year 1875, carried a load of only 718 English pounds, whereas the stagecoach and omnibus, drawn at a trot, carried loads of 1,100 to 1,800 English pounds. The heavy and massive construction of the Roman vehicles, the inadequate system of harnessing, the lack of draught power by the horses of small stature, and the excessive grades of the roads were responsible for the relatively light loads as compared with modern times.

FRONT AXLE OF FOUR-WHEELED VEHICLES TURNED UPON A KINGBOLT

There has been considerable discussion as to whether the front axle of four-wheeled Roman vehicles was a rigid unit, or whether it turned upon a kingbolt as it does in modern vehicles. Some authors claim that the straight course of Roman roads was necessitated by the in-

³ The *as*, or Roman pound, weighed 326.337 grams which is nearly three-fourths of the present English pound avoirdupois weighing 453.59 grams.

⁴ Net loads, exclusive of the weight of the vehicle, are used in this comparison. The 4,500-pound net load for the motor truck is the equivalent of a 9,000-pound gross wheel load.

ability to turn the front axles, and that in rounding a curve in the road it was necessary for the draught animals to drag the front wheels across the surface of the roadway, because the Roman undercarriage

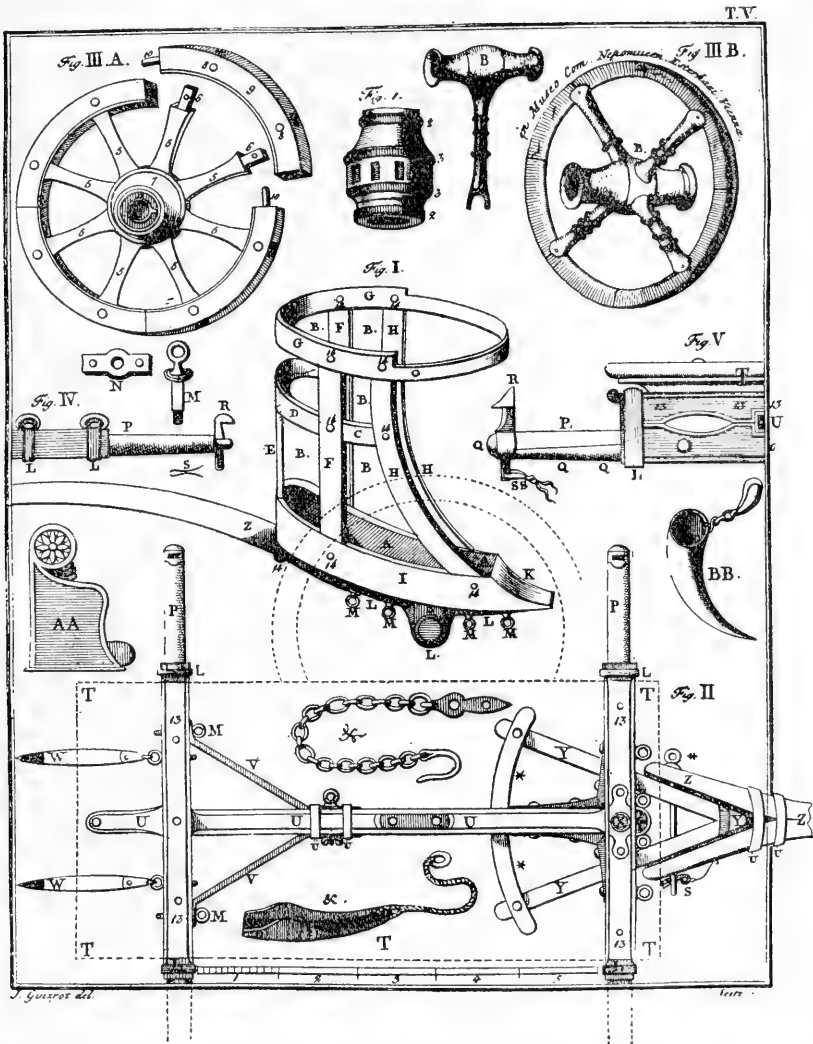


FIGURE 3.—Sketch reproduced from Ginzrot's work (9). At the bottom is shown the detail of the undercarriage common to all Roman four-wheeled vehicles. The kingbolt is shown at X and the wheel plate or rubbing strip at Y.

possessed no kingbolt and wheel plate. This contention seems to be in error. The argument is authentically refuted by Ginzrot (9), who submits a sketch of a typical undercarriage used for all four-wheeled vehicles, which is reproduced in figure 3. Ginzrot lists the names of the various vehicular parts employed by ancient authors, among them

Pollux, who wrote in the second century. His terminology includes both the kingbolt and the wheel plate, or rubbing strip.

ROMAN RULE OF THE ROAD A MOOT QUESTION

The question as to whether the traffic on the Roman roads passed to the right or left of an oncoming vehicle is difficult to answer with certainty. The evidence, however, seems to indicate that the prevalence of the box wagon or postilion method of driving established the rule of the road in any given locality. In the country districts, where the box wagon was in general use, the practice was for the driver to sit on the extreme right side of the seat in order to permit the free play of his right whip hand. Thus he passed to the left so as to gage more accurately the clearance between the wheel hubs of his own and the approaching vehicle. In the city districts, however, where the postilion rode upon the left wheel, or rear horse, so as to permit the most direct use of the right whip hand, it was the custom to pass oncoming vehicles to the right.

When Premier Mussolini came into power, the rural traffic in Italy passed to the left, while the urban custom was to pass to the right. This difference in custom was abolished by an edict of the Premier which made the right-hand rule of the road mandatory everywhere.

In North America, in the Colonial days, although there was no generally accepted rule, the prevailing practice was to pass to the left in accordance with the English custom. The advent of the heavy Conestoga covered freight wagons in Pennsylvania, about the year 1750, with their postilion method of driving, began the establishment of the right-hand rule of the road, which is now universally observed in the United States.

DISTINGUISHING CHARACTERISTICS OF THE ROMAN ROADS

Although undaunted by natural obstacles and great differences in elevation, the Romans took advantage of all natural conditions in order to make the most of the engineering knowledge of their times. They avoided cuts wherever possible, because of inadequate excavating equipment, and they preferred sidehill location to the exclusion of valleys where the foundation problems were more difficult.

No attempt was made to balance cuts and fills either in profile or cross-section. Except for sidehill excavation, open cuts are usually found only in rock. Since no explosives were available at that time and solid rock was removed by the slow and laborious process of wedging and picking, one can readily appreciate their aversion to solid rock excavation. Where rock work was necessary the Romans preferred tunnels to through cuts in order to confine the hand labor

to the essential cross-section. This explains why the number of long tunnels built by the Romans is almost as great as the number of open cuts. Among the outstanding examples of rock cuts, according to Leger (4), is the one on the Appian Way, near Terracine, through a cliff of marble perpendicular to the sea. This cut is 117 feet high, and 98 feet long. Upon the Flaminian Way, at the crossing of the Apennines, Vespasian bored the tunnel of Furlo, which was about 984 feet long.

The Roman roadbuilders followed the passes across the mountain ranges, and made the necessary development by means of switchbacks, in order to attain elevation, but, unfortunately, they permitted excessive grades of as much as 15 to 20 percent. In the early days, approach grades of 10 and 12 percent were common even at bridge approaches in the level plain. Later, however, when the traffic increased considerably, the Romans realized that these steep grades made impracticable the hauling of heavy loads. Consequently, the provincial roads were built without heavy grades.

Curves required rather large radii because of the long teams, sometimes composed of 10 horses driven two abreast. However, in order to avoid deep cuts in sloping terrain the Romans were compelled at times to use curves with short radii. Thus Leger (4) cites an extremely dangerous curve, with a radius of 23 to 26 feet, in a rock cut 11 feet wide, with an approach grade of 15 percent, located near Annecy at the Saint Clair bridge.

The Romans built many important embankments mainly from side borrow. The courses were leveled and rolled, with stone rollers, or rammed carefully. Some of these embankments are of considerable height and length. For example, in the restoration of the Appian Way across the Pontine marshes, the Emperor Trajan made an embankment 39 feet in width, and $17\frac{1}{2}$ miles in length, intercepted by a great number of bridges and arch culverts. Frequently high embankments were flanked by retaining walls. Leger (4) refers to a dike at Arricia, upon the Appian Way, which is 745 feet long, 41 feet wide, and 43 feet in average height, between retaining walls of *peperino* stone.

As a rule Roman roads were distinguished by long tangents, undulating profiles, and crowned surfaces.

DESCRIPTION OF THE MODEL OF THE VIA APPIA

In order to visualize the method of construction, cross-section, and vehicular use of an outstanding Roman road, a model (pl. 1) of the *Via Appia* was built for the Bureau of Public Roads, United States Department of Agriculture, by its modelmaker, H. W. Hendley (pl. 3). The design and construction of this model was based upon

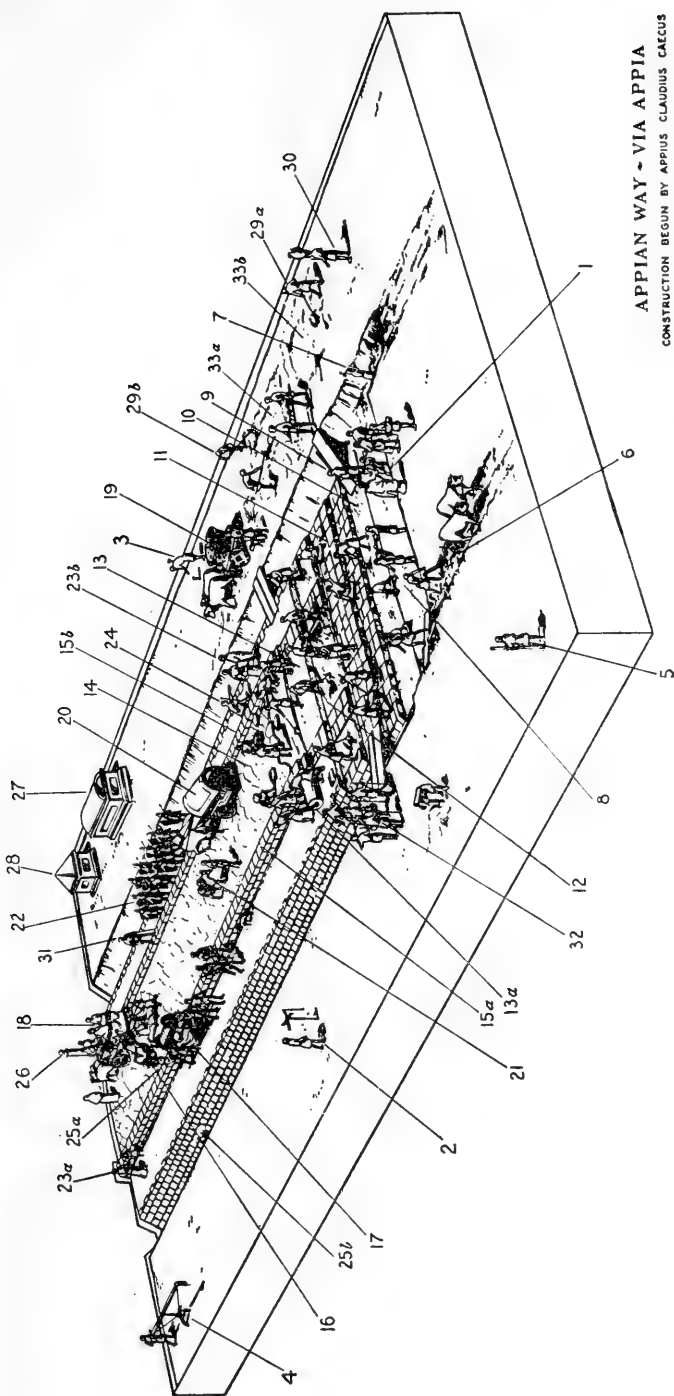
painstaking research, and it is believed to be the first attempt to portray in model form such a variety of information. The model is 4 feet wide by 8 feet long, and is on a scale of $\frac{1}{2}$ inch equals 1 foot.

The numbers on the perspective drawing (fig. 4) are a key to the model and are inclosed in brackets in the following description: In the foreground of the model at [1] the administrator of the work (*curator operis*) is seen discussing ways and means for building the road shown on the flat plans (*depictae species in membranulis*) held by the contractor (*manceps*). The third member of the group, holding the roll of plans under his arm, is the engineer (*architectus*). At [2], one of the engineer's assistants is alining, with a *groma* (10), a stake being driven by another assistant at [3]. A member of the surveying party is shown at [4] running levels with a *chorobates* (11) while his assistant holds a leveling rod at [5].

The model represents a typical roadway on firm upland terrain. Where marshy regions or unstable foundations were encountered, the Roman engineers first built timber-work foundations called *contignata pavimenta*. The timber substructures themselves were called *contignationes*. The planks in the flooring were termed *coaxationes* or *cessionationes* and were made of an oak called *aesculus*, because this wood did not warp or shrink. They covered this timber flooring with a bed of rushes, reeds, or sometimes straw to protect the wood from the destructive effect of the superimposed lime, mixed with other materials. Upon this stratum of reeds or straw was laid the *statumen* or foundation, and the remainder of the construction was prosecuted in the same manner as on the firm ground, with the exception that the total thickness of masonry seems to have been reduced in order to lessen the dead load of the roadway upon the marshy subsoil.

Excavation of the foundation.—Upon solid ground the margins of the roadway were marked by two parallel furrows of a wheel plow (*aratrum currus*), as shown at [6], about 40 feet apart. Following the location of these furrows, two parallel trenches (*sulci* or *fossae*) were excavated [7] to determine the nature of the subsoil and the depth to a solid foundation (*gremium*). The excavators (*fossores*) used a shovel (*pala*), and a combined mattock and pick (*fossoria dolabra*). Then the excavators aided by a porter (*bazulus*) with a basket (*aero*) upon his back, shown at [8], removed the earth between the trenches to the level of the roadbed (*gremium*). A ramp (*pons*) was used by the porter for reaching the elevation of the undisturbed ground surface.

Consolidation of the foundation.—Where unsuitable material was encountered, it was removed and replaced with firm subsoil which was thoroughly tamped with the beetle (*pavicula*) indicated at [9].



APPIAN WAY - VIA APPIA

CONSTRUCTION BEGUN BY APPIUS CLAUDIUS CAECIUS
CENSOR OF ROME, 312 B. C.

ISOMETRIC PROJECTION SHOWING CONSTRUCTION METHODS,
VEHICULAR AND FOOT TRAFFIC ON A ROMAN ROAD

BUREAU OF PUBLIC WORKS
UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

FIGURE 4.—Perspective drawing of the model of the *Via Appia* for use as a key to the numbers shown in the text.

If a firm bed could not be obtained, wooden piles (*fistucationes*) were driven into the foundation. The roadbed (*gremium*) was then carefully shaped and leveled to receive the surfacing materials. Even where the excavation revealed a comparatively firm foundation, the subsoil was always carefully rammed with the *pavicula* before proceeding further.

Bedding course.—Upon the roadbed, prepared as described above, there was spread a bedding course of sand from 4 to 6 inches in thickness, or mortar about 1 inch thick, made of lime and sand or hassock (soft, calcareous limestone). This bedding course, called the *pavimentum*, and indicated at [10], accommodated the irregularities in the undressed lower side of the stones used in the first course of masonry called *statumen*. While spreading the *pavimentum* layer, the mortar worker (*cementarius*) sat upon a stool (*sedecula*) the better to use his long trowel (*trulla*). Probably mortar was spread first to a uniform thickness with a rake (*rastrum*). The lime (*calx*) was slaked in a pit (*lacus*) [33-b] beside the road and later mixed with sand, by means of a long-handled hoe (*rutrum*) [33-a]. Meanwhile, another pit of lime was slaked. The mortar was carried to the road with the aid of a two-man hod. The water for slaking the lime was brought to the pits in earthenware jars carried upon the heads of the water bearers [30]. Sometimes V-shaped wooden troughs were used to conduct the water from the source of supply.

*Statumen.*⁵—Into the *pavimentum* was bedded the *statumen*, or first course, as shown at [11]. This course consisted of two layers of flat stones cemented together with well-tempered lime mortar. The smallest stones were sufficiently large to fill a man's hand, and the largest were ranged along the sides of the causeway to act as a retaining wall. When lime mortar was not available, the stones were cemented with clay. The *statumen* varied in thickness from 10 inches in good ground to 2 feet in bad ground. Since the purpose of this course was to provide a solid foundation, almost any kind of stone was used. The softer stone used in the *statumen* and in the two next courses, the *rudus* and *nucleus*, was called *lapidicinae molles* or *temperatae*, to distinguish it from the *lapidicinae durae*, or hard stone, reserved for the wearing surface (*summum dorsum*).

Ordinary masons (*structores*) placed the stones for the *statumen* course. To cut the stone, they used the chisel (*scalprum*) and mallet (*malleus*), iron wedges (*cunei*), the adz (*ascia*), and the saw (*serra*). Masons also used the trowel (*trulla*), the mortar bucket (*fidelia*), and the level (*libella*). The heavier stones were suspended by cords

⁵ All later writers have followed the lead of Nicolas Bergier (12), who wrote in 1622, in naming the four principal courses of Roman roads as *statumen*, *rudus*, *nucleus*, and *summa crusta*. Bergier states, however, that his only authority was Vitruvius (11), who wrote at the beginning of the Christian era, and who described the four courses in pavements used in the construction of buildings.

from poles (*palangae*) supported upon the shoulders of the porters [32]. To move these stones into position they employed the crow-bar (*vectis*).

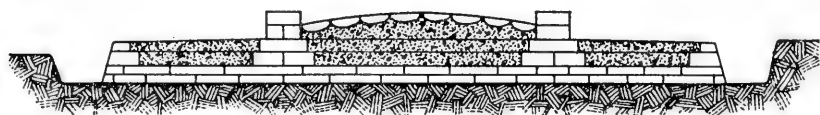
Rudus.—This second bed, shown on the key sketch at [12], was made of broken stones smaller than those used in the *statumen*, and mixed with lime. Isidore, the Greek architect of the sixth century, who completed the Church of Saint Sophia at Constantinople, called material of this character *rudus*. When this layer consisted of newly broken stone, it was called *rudus novum*, and to three parts of stone there was added one part of quicklime. When reclaimed aggregate (*rudus redivivum*) was used, mixed in the proportions of two parts of lime to five parts of aggregate, this composition was known as *rudratio*. The beetle or rammer was used to consolidate, level, and smooth the courses. Whether this layer was constructed of new or old material, it was about 9 inches thick after compaction.

The first step in laying this course consisted in spreading a layer of mortar over the *statumen* with a rake. Then the gravel or debris was dumped upon the mortar and tamped into it with a beetle in such a manner that the aggregate was left protruding. This rough surface assured a substantial bond with the next layer (*nucleus*). When aggregate for this type of work was hauled for a considerable distance, the 2-wheeled *plaustrum* was used. This vehicle had a basket body, used for carrying heavy loads, and was generally drawn by oxen as shown at [19].

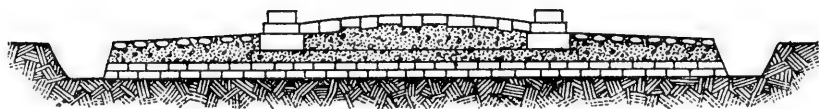
Nucleus.—Into the roughened surface of the preceding course (*rudus*), there was bonded the third layer, commonly called the *nucleus*, or kernel [13], but sometimes referred to as the pudding or pap. This layer of concrete consisted of small gravel, coarse sand, and hot lime. This *nucleus* was placed in successive layers, each compacted by a roller (*cylindrus*) [13-a]. At the side *margines* the *nucleus* was about 1 foot thick and in the central *agger* the thickness was increased to 1½ feet in order to form the crown. Into this freshly laid mortar was bedded the wearing surface, or *summa crusta*. The *nucleus* formed the wearing surface for the side roads or *margines*, which were at a lower level than the central roadway or *agger*.

Summa crusta or *summum dorsum*.—This wearing course, called the *summa crusta* or *summum dorsum*, illustrated at [14], was bedded in the freshly laid *nucleus* within the *agger* or central portion of the roadway between the side curbs. The high crown, of about 6 inches in the 16 Roman feet (15½ English feet), between the side curbs (*umbones*), was designed to facilitate the passage of the projecting hubs of chariots and for surface drainage. Side drains (*cloacae*), an inlet of which is shown at [25-a] and an outlet at [25-b], were built at regular intervals through the side curbs (*umbones*), and under the *margines*, to the side ditches (*fossae*).

Especially on important roads like the Appian Way the *summa crusta* was made of hard, durable, wear-resisting stone like *silex*, a flintlike lava. This stone was laid in the form of pentagons, hexagons, or irregular polygons, from 1 to 3 feet in diameter and some 6 inches in thickness. The upper surface was smooth, but the bedded under side was left rough. The joints were fitted so closely as to be scarcely discernible. This type of masonry was known as *opus incertum*. If volcanic *silex* was not available, other hard stone was used, but dressed and laid in the same manner. Occasionally the surface of the road was made of concrete. Sometimes blocks of schistose stone, similar to Belgian block, were laid on edge. This type of construction has been found upon a section of the Fosse Way in Britain. The less important roads were frequently surfaced with gravel.



Cross Section of the Appian Way
by Cresy



Cross Section of the Appian Way
by Leger

FIGURE 5.—Cross-section of the *Via Appia* as shown by Cresy (6) and Leger (4).

Side curbs (umbones).—The side curbs, or *umbones*, [15-a and b], projected 18 inches above the *margines*, and were 2 feet wide. They were built upon a foundation of large stones resting upon the *statumen*. Mounting blocks (*gradus*) were placed along the side curbs at regular intervals.

Dimensions of the Via Appia.—The total thickness of the four courses described above varied from 3 to 4½ feet. The overall width of the *Via Appia* at the surface was about 36 Roman feet (35 English feet), of which the central *aggar* constituted 15½ English feet, the two *umbones* each 2 English feet, and the two *margines* each 7¾ English feet. Cross-sections of the road, by Edward Cresy (6), in 1847, and by Alfred Leger (4), in 1875, are shown in figure 5.

Typical traffic.—The chariot (*currus*) [16] was probably the vehicle most commonly used by the ancient Romans. Although it found its greatest usefulness as an instrument of war, the lightness of its construction made it suitable for all kinds of rapid transportation. It had two wheels, was built to hold two people, and was drawn by two or more horses. There were many different types of Roman vehicles such as the luxurious litter (*lectica*) [17], the humble *rheda* [18], a family or stage coach, and the still more humble farm cart or *plaustrum* [19]. The *lectica* was carried by slaves with the aid of poles, run through rings attached to the body of the litter, or fastened by cords or thongs. The litter bearers (*lecticarii*) were usually Syrian or Cappadocian slaves, often dressed in bright red cloaks made of fine wool from Canusium. For this reason they were also called *canusinati*. In and near the cities slaves preceded the *lectica* to clear the way with the words "Give place to my lord." These harbingers were called *anteambulones*.

The *carpentum* [20] was a covered two-wheeled carriage used for general travel and by women upon state occasions.

The pack animal (*clitellarius*) [21] carrying a small amount of baggage in panniers, supported by a pack saddle, illustrates the poor man's method of traveling.

The Roman infantry (*legionarii*) on the march [22] were permitted to walk in the central roadway or on the side roads, and the side curb provided an elevated walk for the commanding officer (*centurio*) [31].

Near the cities and towns the usual pedestrians were encountered [23-a and b] and the curb was the favorite resting place for the beggar (*aeruscator*) [24].

Milestones.—The Romans placed milestones (*milliarium*) [26], 1,000 Roman paces apart (4,859 English feet), along their principal highways. In the vicinity of Rome these milestones, according to Bergier (12), represented the distances not from the city gates, but from the golden milestone (*milliarium aureum*) erected by Augustus, in the Roman Forum, to mark the origin of all the great military roads. Beyond 100 miles from Rome, and in the provinces, the milestones showed the distances to the nearest principal town.

Monuments.—Outside of Rome and the large cities, the roads were bordered with temples and statues, dedicated to various gods, and with monuments, tombs, and mausoleums. The latter, no doubt, were relegated beyond the walls of the city for reasons of sanitation. At [27] may be seen a sarcophagus, the tomb of a prominent Roman citizen. A *cenotaphium*, or monument erected in memory of a celebrated Roman, is shown at [28].

This concludes the description of the model, replicas of which are now on display in the United States National Museum, at Washington, D. C.; in the New York Museum of Science and Industry; and in the Rosenwald Museum of Science and Industry, in Chicago. Close-up views of the outstanding features of the model are shown in plates 2 and 3.

COST OF CONSTRUCTION OF THE *VIA APPIA*

Based upon the calculation of Leger (4), an average Roman military road would cost \$116,000 a mile to reproduce in the United States in 1926. This calculation is based upon an average road width of 12 Roman feet between side borders, with two *margines* each 2 feet wide, and an *agger* of $3\frac{1}{4}$ feet in thickness; all built without the aid of statute labor or legionary soldiers. Computed upon the basis of the price of labor in France, in 1875, Leger estimates a cost of \$34,200 a mile. According to the statistics of the United States Department of Labor (13), the index number for wage rates in 1875 was 67, and in 1926 it was 229. Therefore, a comparable cost in the United States in 1926, based upon Leger's figures for 1875, is \$116,300.

The 1926 cost of the *Via Appia*, however, which was 36 Roman feet in width, with a central *agger* of 16 feet, elevated curbs on each side 2 feet wide, *margines* each 8 feet in width, and a total thickness of about $3\frac{1}{2}$ feet, would amount to considerably more than the average military road used as a basis for the foregoing estimate of cost. The reproduction cost of the *Via Appia* in the United States, in 1926, is estimated by the author, at \$300,000 a mile.

SOURCES OF ROMAN HIGHWAY REVENUE

The Roman military roads were constructed by the State and maintained by a tax assessed upon real property. Various means, such as donations, statute labor, and requisitions were used to obtain road funds.

Before the establishment of the public register of land for assessment purposes, the cost of road and bridge maintenance was defrayed from the proceeds of tolls. The law allotted to the Censors, and later to the *viocuri* and the *curatores viarum*, the duty of fixing these tolls, also the making of awards to contractors, and the supervision of repairs. In time the tolls were collected by a tax-collecting administration, and more regular maintenance was assured by a direct tax.

The parish and secondary roads were built at the expense of the towns and boroughs, with the aid of special donations, and maintained by statute labor provided by the owners of adjoining property.

Oaths for 3 days' labor, paid in silver (*impensae*) or in kind (*operae*) were regulated by the magistrates. The taxes were based upon the area of land affected, or upon the number of interested inhabitants.

Statute labor for maintenance of the roads was at first resented by the people and classed with those servile contributions which did not apply to Roman citizens. Later, when the right of citizenship was extended to everyone, Theodosius, Honorius, and Arcadius, in order to assure the upkeep of the roads, ranked statute labor among the honorable contributions, owed in principle by all citizens, even by the Emperor himself.

The statute labor of the Romans established the precedent for the system of road upkeep which is found incorporated in English laws from the time of the Middle Ages. The same system prevailed in France under the name of *les corvées*. One of the main causes for the French Revolution was attributed to the inherent defects in this law, which permitted all sorts of maladministration. Prior to the advent of the automobile, when the roads of the United States were in a deplorable condition, much of road maintenance was carried on by voluntary labor provided for by similar statute-labor legislation. The motor age in America, however, has brought about a rapid abandonment of this type of public service and substituted for it the more economical contract system.

DISINTEGRATION OF ROMAN ROADS DURING THE MIDDLE AGES

The foregoing discussion illustrates the vast difference between roads of the ancient Romans, built by slow and laborious methods, with the aid of manual labor, and used by relatively light horse-, mule-, or ox-drawn vehicles, and modern highways built rapidly by mechanical methods, to withstand the destructive wear and tear to which they are subjected by motor vehicles.

Built with a tremendous waste of material and labor, the great depth and solidity of the Roman roads have caused them to resist disintegration during many centuries and to survive as a monument to their builders. An artist's conception of a high-type Roman road as it existed during the days of the Empire is shown in plate 4. The Romans relied upon massive construction to support the traffic of their time, whereas the modern road builder proceeds upon the assumption that the pavement should act as a wearing surface and roof to protect the subsoil which bears the load. The present-day road builders have constructed in this manner more extensive systems of roads which cost much less than those of the Romans. It is doubtful, however, whether the lighter and more economical construction of our time could withstand, as have the pavements of the Romans, the destructive effects of climatic changes over many centuries.

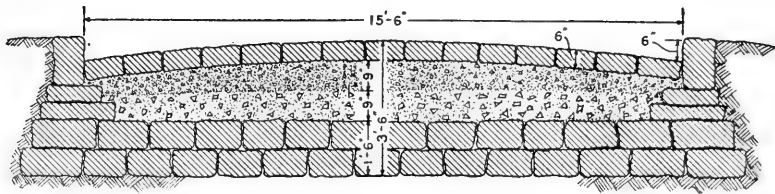
The system of Gallic-Roman roads lasted from the fall of the Empire of the West, in A. D. 476, until the middle of the seventh century. The roads as a system seem to have disappeared gradually in the following century. With the rise of the feudal system on the Continent, the Roman roads were destroyed because the people saw in them a means of transportation for robber bands and conquering armies. Thus, under the chaotic political conditions which prevailed during the Middle Ages, roads fell into disuse and repairs were neglected.

In England, with the Anglo-Saxon invasion in the fifth century, there began a period of 1,400 years of neglect and spoliation of the Roman roads. English names were given them and they were attributed to a fabulous origin. The greatest destruction of the Roman roads, however, occurred in the eighteenth century, when they were robbed of their materials and destroyed in order to make the turn-pikes. The roads which escaped the ravages of man seem to be little affected by the centuries of neglect (14). They are found generally under an accumulation of soil which acts as a protective covering and an aid to their preservation.

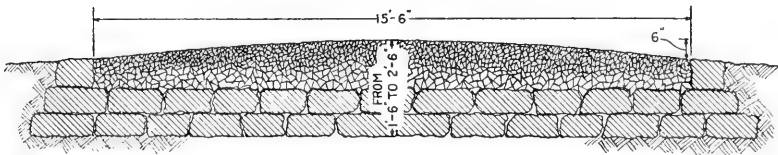
MODERN ROAD CROSS SECTION MORE ECONOMICAL THAN THAT OF THE ROMANS

At the close of the Middle Ages, when social conditions became sufficiently stabilized to permit the resumption of road building under the supervision of organized governments, the cross sections of the roads bore a strong resemblance to those employed by the ancient Romans. Thus the designs adopted by Trésaguet, in France, and Telford, in England, as shown in figure 6, with their subbases of large stones, are a reversion to the heavy *statumen* course of the Roman road builders. Toward the close of the eighteenth century the idea that the subgrade soil was the sole support for the weight of traffic was still in its embryonic stage.

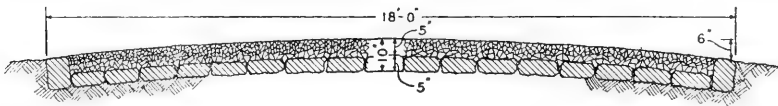
It was not until the early part of the nineteenth century that John Loudon Macadam, the English road builder, eliminated the heavy Telford subbase, which harked back to Roman times, and substituted in its place a base course composed of broken stone with a maximum weight of 6 ounces (approximately 2½ inches in size). Thus it was Macadam who argued that "all the old roads of the kingdom have been OVERDONE" and proceeded resolutely to omit the heavy stone subbase from the roads built under his direction (15). His philosophy, which at that time was considered quackery by some, was as follows: "The roads can never be rendered thus perfectly secure until the following principles be fully understood, admitted, and acted upon: namely, that it is the native soil which really supports



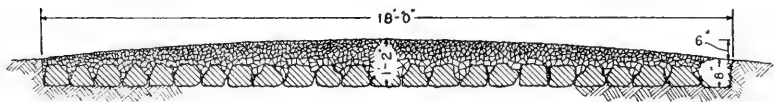
ANCIENT ROMAN 2-LANE MILITARY ROAD.



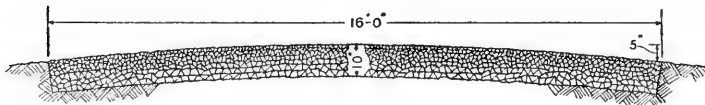
FRENCH ROAD (ROMAN METHOD) PREVIOUS TO 1775.



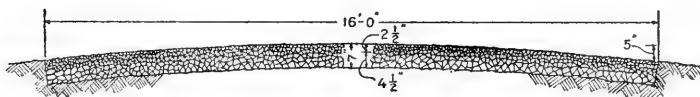
TRÉSAGUET ROAD, FRANCE, 1775 TO 1830.



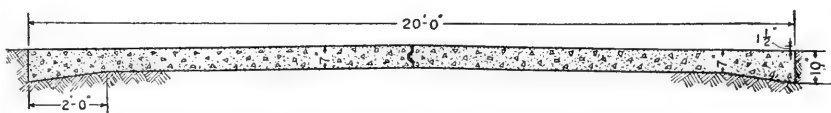
TELFORD ROAD, ENGLAND, 1820.



ORIGINAL MACADAM ROAD, ENGLAND, 1816.



MACADAM ROAD, UNITED STATES, 1900.



HEAVY-DUTY 2-LANE CONCRETE PAVEMENT, UNITED STATES, 1934.

FIGURE 6.—Cross-sections comparing the thickness of road surfaces in ancient and modern times.

the weight of traffic; that while it is preserved in a dry state, it will carry any weight without sinking, and that it does in fact carry the road and the carriages also; that this native soil must previously be made quite dry, and a covering impenetrable to rain must then be placed over it to preserve it in that dry state; that the thickness of a road should only be regulated by the quantity of material necessary to form such impervious covering, and never by any reference to its *own* power of carrying weight" (8). It was, therefore, Macadam who first designed a road surface to act as a roof and wearing surface to protect the load-supporting subgrade. This is the fundamental principle upon which modern road design is founded. As a consequence the extreme thickness of $3\frac{1}{2}$ to 5 feet, used on the great Roman highways, was considerably modified and reduced by road builders in the period following the Renaissance, until in the cross-section of John Loudon Macadam the thickness was reduced to 10 inches. A still further reduction in thickness has been made possible by modern methods of road design and construction. In figure 6 is shown a high-type rigid pavement suitable for use on a 2-lane superhighway in the United States. This surface is capable of withstanding, for an indefinite period, concentrated wheel loads of 9,000 pounds, under motor trucks traveling at the high speed of 50 miles an hour.

Times have changed. The horse-drawn vehicle, the accepted mode of travel since the dawn of historic time, has been supplanted by mechanical transport. As late as the eighteenth century, research in the field of transportation was directed toward the rediscovery of the lost arts of the ancients. Few new ideas were added to the existing store of knowledge. In the nineteenth century, however, engineers on the Continent and in England departed from the beaten track of experience in search of more serviceable types of surface. Thus there were developed the designs of Trésaguet in France and Telford and Macadam in England. These surfaces were adequate as long as the wagon prevailed. With the twentieth century, however, there was introduced a vehicle totally different from any hitherto known. The horseless wagon revolutionized methods of road construction and design. Lacking precedents to guide them, engineers were hard pressed to design highways suitable to withstand the destructive effects of the new traffic.

Nevertheless, out of the maze of observation and research there is being formulated, bit by bit, the new science of highway engineering. How far we have advanced may be measured best by contrasting present conditions with those existing 2,000 years ago. For example, the modern road surface averages roughly one-sixth of the thickness and cost of the ancient Roman road, whereas the present-

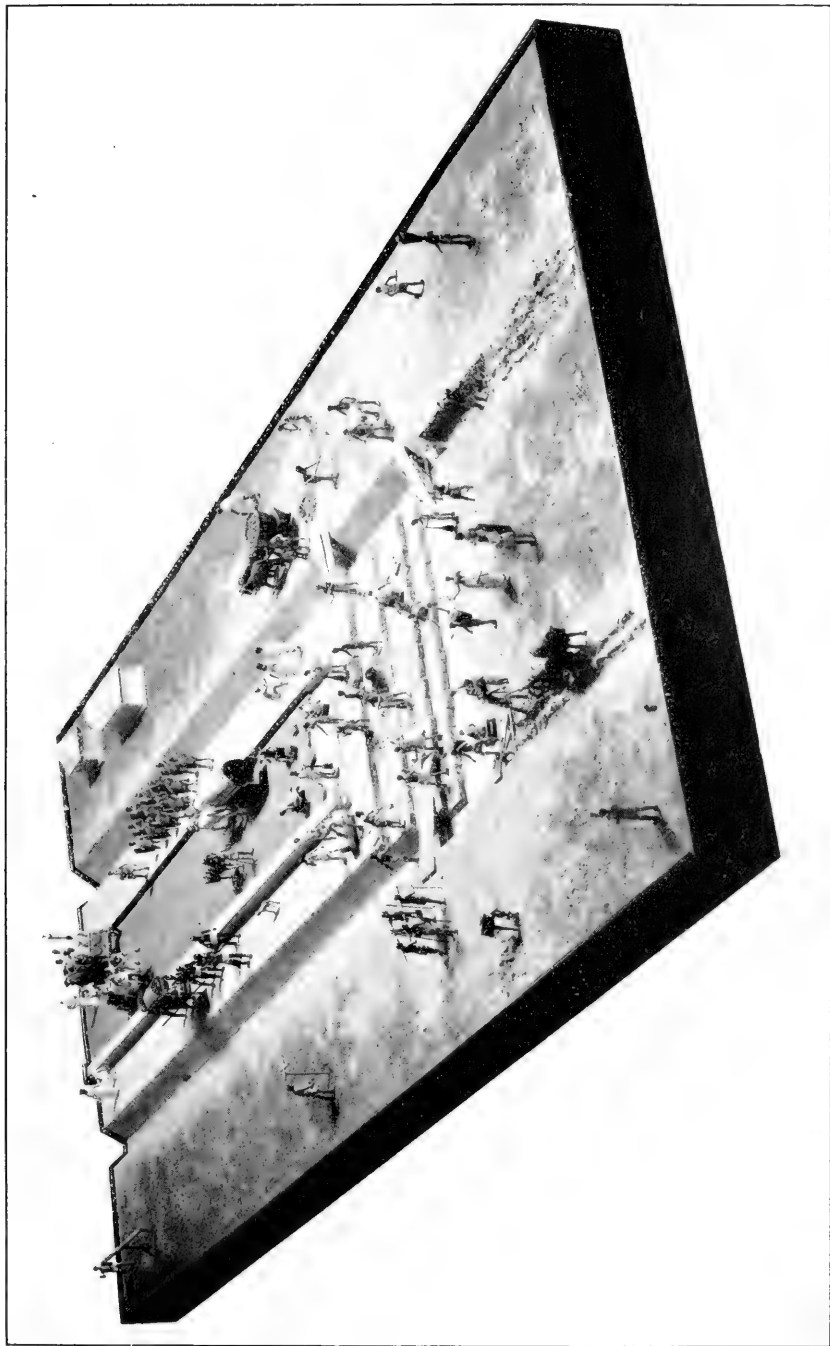
day motor truck has a net wheel load which is more than six times as great as that of the Roman freight-carrying vehicle.

Redistribution of our population and decentralization of industry, with all their beneficial effects, are following in the wake of the cyclical change in our methods of transportation. Although better things are in store for us in the sphere of land transport, the memory of the *Via Appia* will serve always as an inspiration to the road builder.

LITERATURE CITED

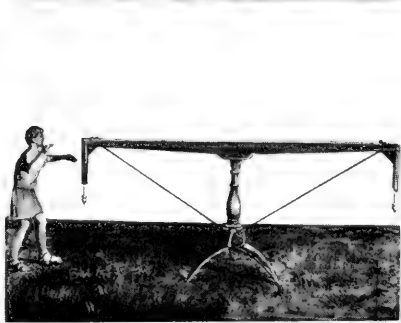
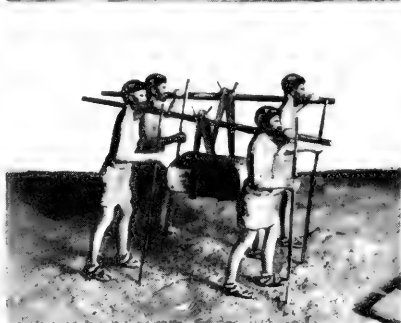
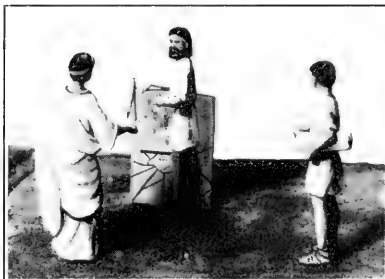
1. SLATER, DAVID ANSELL
1908. *The Silvae of Statius*, translated from the Latin, with an introduction and notes. Oxford.
2. LANCASTER, SAMUEL CHRISTOPHER
1926. *The Columbia, America's Great Highway*. Portland, Ore.
3. SAINT LUKE
The Acts of the Apostles, chapter 28, verses 13 to 15, written about A. D. 65.
4. LEGER, ALFRED
1875. *Les travaux publics les mines et la métallurgie aux temps des Romains*. Paris.
5. RIPOSTELLI, J., partie païenne. Marucchi, H., partie chrétienne.
1908. *La via Appia, à l'époque Romaine et de nos jours; histoire et description*. Rome.
6. CRESY, EDWARD
1847. *An encyclopaedia of civil engineering, historical, theoretical, and practical*. London.
7. MOONEY, WILLIAM WEST
1920. *Travel among the ancient Romans*. Boston.
8. McADAM, JOHN LOUDON
1820. *Remarks on the present system of roadmaking; with observations, deduced from practice and experience, with a view to the revision of existing laws, and the introduction of improvement in the method of making, repairing, and preserving roads, and defending the road funds from misapplication*. London.
9. GINZROT, JOHANN CHRISTIAN
1817. *Die Wagen und Fahrwerke der Griechen und Römer und anderer alten Völker; nebst der Bespannung, Zäumung und Verzierung ihrer Zug-Reit-und Last-Thiere*. Munich.
10. LEGNAZZI, E. N.
1887. *Del catasto Romano e di alcuni strumenti antichi di geodesia*. Verona, Italy.
11. GWILT, JOSEPH
1860. *The architecture of Marcus Vitruvius Pollio in 10 books, translated from the Latin*. London.
RUSCONI, GIO ANTONIO
1590. *Della architettura con centosessanta figure dissegnate dal medesimo, secondo i precetti di Vitruvio e con chiarezza, e breuità dichiarate, libri dieci*. Venice.
12. BERGIER, NICOLAS
1728. *Historie des grands chemins de l'empire Romain*. Brussels.

13. UNITED STATES DEPARTMENT OF LABOR, BUREAU OF LABOR STATISTICS.
1929. History of Wages in the United States from Colonial Times until
1928. Bull. 499.
14. CODRINGTON, THOMAS
1918. Roman roads in Britain. London.
15. EDGEWORTH, RICHARD LOVELL
1817. An essay on the construction of roads and carriages. London.
16. PARTHEY, G. and PINDER, M.
1848. Itinerarium Antonini Avgvsti et Hierosolymitanvm ex libris many-
scriptis ediderunt. Berlin.

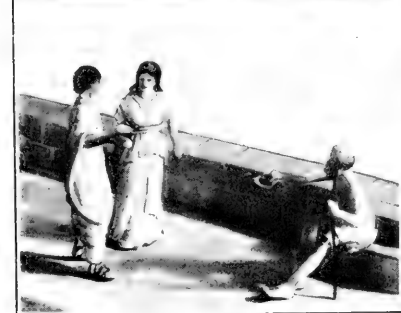
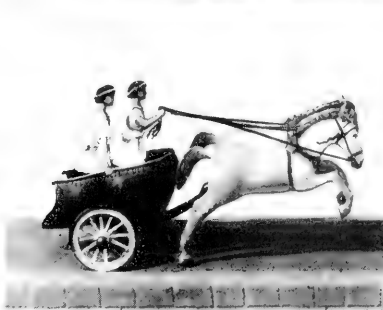
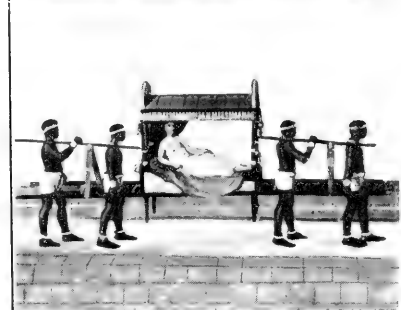
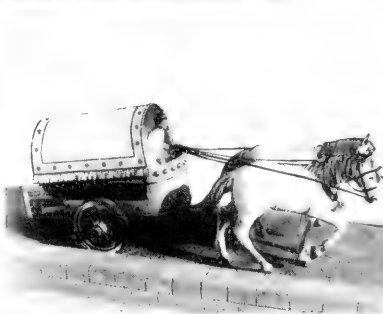
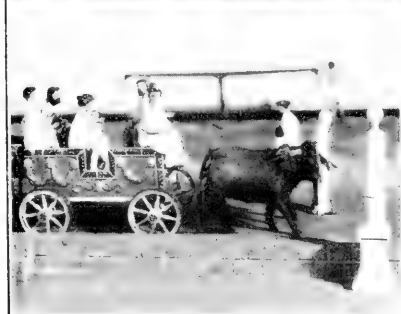


Photograph by J. K. Hillers.

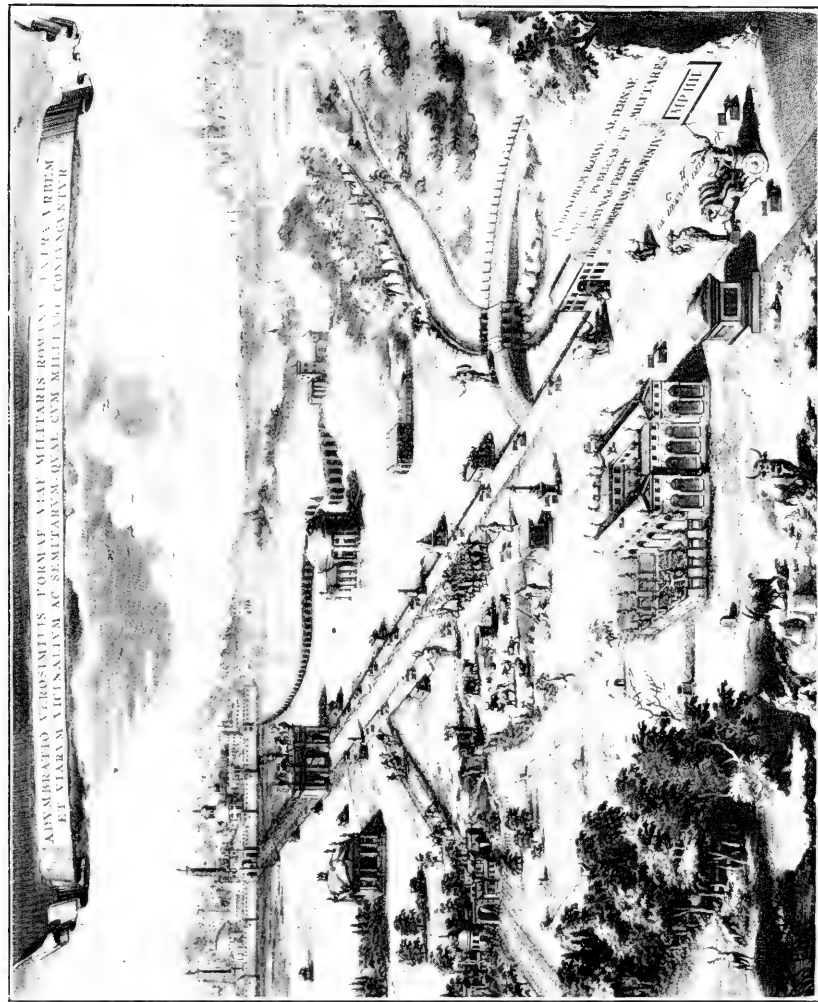
MODEL OF THE "VIA APPIA" MADE BY THE BUREAU OF PUBLIC ROADS, UNITED STATES DEPARTMENT OF AGRICULTURE.



CLOSE-UP VIEWS OF THE "VIA APPIA" MODEL.



CLOSE-UP VIEWS OF THE "VIA APPIA" MODEL AND THE MODELMAKER.



A TYPICAL ROMAN MILITARY ROAD OR PUBLIC WAY.

From Berger (12).

SMITHSONIAN ARCHEOLOGICAL PROJECTS CONDUCTED UNDER THE FEDERAL EMERGENCY RELIEF ADMINISTRATION, 1933-34

By M. W. STIRLING

Chief, Bureau of American Ethnology

[With 10 plates]

When the President's Civil Works Administration program was inaugurated for the winter of 1933-34, under the Federal Emergency Relief, archeological projects were proposed by the Smithsonian Institution for the States of Florida, Georgia, North Carolina, Tennessee, and California, and quotas of relief labor were allotted for each of these States. Inasmuch as proper supervision was essential for successful scientific results on these projects, provision was made for the salaries of trained archeologists. Excavations were begun during the latter half of December 1933, and this work continued throughout the winter, giving employment to approximately 1,500 men.

Because of the opportunity to make use of large laboring crews, sites were selected which ordinarily would not have been practicable to work because of the unusual amount of excavation necessary to work them successfully. The final results proved to be more than satisfactory. A great fund of archeological information has been accumulated regarding some of the hitherto little-known sections of the country. These results were due to the fine cooperation of both Federal and State relief officials, who did all in their power to assist during trying times, and also to the excellent staff of trained supervisors who willingly gave their time, in some instances at a considerable personal sacrifice, to the completion of the projects to which they were assigned. The crews of men engaged on the various excavations exhibited real interest in the work, and without exception excellent morale was maintained.

At the present writing, it has, of course, not been possible to make complete studies of the notes and collections obtained from the various sites. The present brief article pretends only to give a general

preliminary description of each of the projects. Detailed accounts of each will be published when it becomes possible to complete the study of the materials collected. Credit for the success of the various excavations belongs entirely to the supervisors conducting the individual projects.

The work in California was in charge of Dr. W. D. Strong, of the staff of the Bureau of American Ethnology, assisted by W. M. Walker, also of the Bureau's staff. Dr. F. H. H. Roberts, Jr., of the Bureau of American Ethnology, assisted by M. B. Chambers, conducted the work in Tennessee. The North Carolina project was operated jointly by W. B. Colburn and J. D. Jennings. Dr. Arthur Kelly, assisted by James Ford, conducted the work in Georgia in cooperation with the Society for Georgia Archaeology at Macon. The several projects in the State of Florida were under the general supervision of the writer. The excavations at Perico Island in Manatee County and at Englewood in Sarasota County were under the immediate supervision of Marshall Newman. The four mounds excavated on the Little Manatee River in Manatee County were in charge of D. L. Reichard. The projects at Belle Glade in Palm Beach County were under the direction of G. M. Stirling. The excavation of the mound at Ormond Beach in Volusia County was in charge of J. D. Jennings, and the two sites excavated on Canaveral Peninsula in Brevard County were under the direction of Dr. George Woodbury, assisted by Erik K. Reed.

In this brief report it is impossible to mention the names of all those individuals whose cooperation made possible the success of the undertaking. The two men whose interest made possible the inauguration of the work and whose constant aid brought about its successful conclusion were Harry Hopkins and Julius Stone, of the Federal Emergency Relief Administration. While the projects were under way in the field, a great deal of administrative work was necessary for their successful continuation. The burden of this aspect of the projects was borne by Dr. Alexander Wetmore, Assistant Secretary of the Smithsonian Institution, assisted by F. M. Setzler, United States National Museum.

Descriptions of the various projects follow. The material for the preparation of this article was obtained largely from the supervisors of the various projects.

FLORIDA

INTRODUCTION

Prior to discussing the individual sites excavated in Florida under the present program, a few remarks based on the writer's archeological experience in the region may serve to point out some of the

problems involved. In early historic times the northern half of the Florida peninsula was occupied by tribes belonging to the Timucuan stock. The region from Lake Okeechobee south, including the Florida Keys and extending from the Gulf to the Atlantic, was occupied by the Calusa Indians. Archeologically the northern half of the State falls into two areas: that of the Gulf coast, which extends from the Caloosahatchee River to the State line, is characterized by the occurrence of a high grade pottery typically decorated by negative designs or bands set off by stippled areas. Flexed and secondary burials in low sand mounds are characteristic. The Atlantic coast area extends from Palm Beach to the mouth of the St. Johns River and is characterized by the occurrence of a poor grade of pottery which is usually undecorated or check stamped. Burials are usually extended, and sand burial mounds are often much larger and higher than on the Gulf coast. Large sand mounds without burials frequently occur.

The region of the Calusa Indians forms an archeological unit, although showing a definite relationship to the two areas bordering it on the north. The use of the spear thrower, and bone projectile points, and the occurrence of characteristic carved wooden plaques, are typical features of the material culture. All of the prehistoric sites examined in this area seem to be rather closely related. No site has as yet been found which does not appear to tie up closely with the Calusa. The material from prehistoric sites differs but little from that found in the early historic locations, save for the absence of European trade goods.

All of the prehistoric sites of Florida, thus far known, form part of the general Southeastern culture area to the north and west and have undoubtedly been derived from that direction. It is significant to note that there appears to be a general absence of Antillean influence in the peninsula. In the past, several attempts have been made to demonstrate the existence of such contacts, but the evidence is unconvincing. There were undoubtedly some connections in prehistoric times between the peoples of Florida and those of the West Indies, yet it is remarkable how completely absent is the material evidence of such contacts, which must have been culturally unimportant. In spite of the proximity of the Bahamas to Florida, the archeology of these islands belongs definitely to the Antilles.

In spite of the truly enormous extent of some of the Florida shell mounds, the writer has been repeatedly impressed by the cultural uniformity exhibited. The largest shell heaps have not shown important cultural changes from bottom to top, except for those brought about by European contacts. Present evidence seems to indicate that Florida was one of the last sections of the Southeast to

be populated by the Indians, and that this migration was so late that no marked cultural changes had time to develop. The excavations herein discussed tend to strengthen this general viewpoint.

BELLE GLADE SITE, PALM BEACH COUNTY

The Belle Glade site consists of a refuse mound approximately 100 by 150 yards in extent and an adjoining sand burial mound. The site is located in the Everglades a mile and a half west of the town of Belle Glade, an area formerly occupied by the Calusa Indians.

A section 70 by 20 feet was excavated near the northwest part of the shell mound, which yielded a quantity of potsherds and artifacts of bone, shell, stone, and wood. The shell mound reached a maximum height of 7 feet from its base in the area explored. The base of the mound now rests 2 feet or more below the surface of the surrounding land, and on its outer margin shows an accumulation of a foot or more of muck on top of the shell and debris. On the south part of the mound there is a slight elevation about 2 feet higher than the general level of the mound that may represent a platform upon which a structure was built. The site was located between the forks of the Democrat River, a stream that has now been largely obliterated as a result of drainage operations. The burial mound was on the opposite side of the minor fork from the habitation site.

Preliminary investigations seem to show a rather static culture at this site, the same type of objects occurring at all levels. The bone implements consisted in the main of arrow and spear points, awls, and long pins. Deer-horn artifacts were plentiful and included awls, flaking implements, and adz holders. An interesting object recovered is what seems to have been a deer headdress consisting of a small portion of the skull with the antlers attached. The antlers have been polished and hollowed out so as to make them light in weight.

Marine shells were used extensively in the manufacture of implements and utensils. Conch shell "hoes", adzes, cups, spoons, pendants, plummets, and other ornaments were abundant at the site. Shell, as a raw material, largely replaced stone in this region, which is virtually devoid of any suitable rock for use in the fabrication of artifacts. Some stone artifacts, however, were found. These included elbow-shaped sandstone pipes, rubbing stones, and chipped points or knives.

A great number of houseposts were uncovered during the excavation. The position of these in the ground gave little information about the house plans beyond showing a rectilinear type of construction.

Two dumbbell-shaped wooden pestles were excavated from the shell mound. The pottery is mainly undecorated. Whenever decoration occurs, it consists of check stamp with some incising. A few sherds show use of a fugitive red slip. The prevailing forms seem to have been bowls.

No sterile layers occurred in the refuse mound, indicating a continuous occupation, although probably seasonal, as this area would have been flooded in the rainy season. A large collection of animal, bird, and fish bones, and shells was made. These remains indicate a diet of deer, alligators, turtles, raccoons, opossums, turkeys, water-fowl, fish, and shellfish, including many marine forms.

The burial mound, in contrast with the habitation mound, showed two or three different periods of use. The first period was a short occupancy of the site as a place of habitation. The second was the construction of a low burial mound of muck. Following this, a sand mound was built over the old muck burial mound. In front of this new sand mound and facing the habitation site, across the stream, a pavement of limestone rock was constructed, resting in part on the old burial ground. This first sand mound seems to have been destroyed by a hurricane, as the area around it has been covered by water-washed sand containing many complete and broken human bones. Two small but distinct habitation strata occur in this water-deposited material. Following this period the second sand mound was constructed, that is, the present visible one. This latter mound extended into the historic period, as a few of the burials near the surface were accompanied by glass beads.

In all, there were 6 distinguishable periods of use of this site, 3 as a place of habitation and 3 as a burial mound. During its history there was no apparent radical change in culture, the material from all strata closely resembling that from the adjacent shell mound.

Carved wooden objects were recovered from the water-deposited sand from the first sand mound. These included several carved bird heads, a seat in the form of an otter, and parts of two plaques (pl. 1, figs. 1 and 2), similar to those found at Key Marco. In the muck near the river bank and unassociated with any stratum of the mound, a four-legged wooden stool, a wooden canoe paddle, and two stirring paddles were uncovered. Also from the muck near these, three intricately decorated bone pins were found.

The early muck burial mound contained a tangled mass of burials. Each new interment seems to have disturbed several former burials, resulting in an almost solid mass of skeletal material. Artifacts rarely accompanied the burials. The few found may have dropped in by accident and may not have been funeral offerings. The artifacts from this stratum consist mostly of bone pins that may have been

in the hair when the burials were made. Among these bones was found the remains of a cup or bowl made from a human skull. The undisturbed burials were nearly all extended on the back with no regard for direction.

The second burial period, or the first sand mound, is represented only by disturbed burials. Some of the lower burials in the sand under the mound may belong to these, as no stratigraphy shows in the white sand and as sand extends down to the muck to an absolute level below that of some of the water-deposited material. These deeply deposited burials in the sand mound are also extended on the back.

The burials in the second sand mound show the same type of interment. Several near the surface were accompanied by glass beads. Two of the burials near the surface had tubular shell beads with them, and one had been buried with a dagger manufactured from a human femur. Only those burials that were near the surface were accompanied by cultural remains. As these were mostly articles of a post-European nature, a change in burial custom may be indicated.

Three logs 7 feet long and averaging 4 inches thick, which had apparently formed steps, were located deep in the mound near the northeast side.

The importance of the Belle Glade site lies in the wide range of the material collected. Here, for the first time in Florida, there is a representative collection of habitation shellmound artifacts, burial furniture, and skeletal material all from one site. The site will also give the opportunity to study any cultural or physical changes that may have taken place within this group. This is a unique opportunity, as definite stratigraphy is rare in Florida. Another important feature here is the correlation that is possible with the wooden material found by Cushing at Key Marco, which tends to link the two sites together culturally. There can be little doubt that both the Marco site and the Belle Glade site mark former villages of the Calusa Indians.

MOUNDS ON PERICO ISLAND, MANATEE COUNTY

On the western side of Perico Island near Bradenton is a group of three shell mounds extending in a north and south direction and approximately 100 yards distant from Sarasota Bay. The most conspicuous mound of the group is a large shell habitation mound about 900 feet in length by 120 feet in width. One thousand feet southwest of this mound is another similar smaller mound. From the southern edge of the large habitation mound a shell ridge extends in a southwesterly direction terminating in a circular shell burial mound, and northeast of this mound is a small burial area on the edge of a mangrove swamp.

A cross-section was made through the smaller habitation mound; the burial mound was completely excavated and as much of the burial area was cleared out as the high water table permitted. The material of which the burial mound was constructed was a mixture of sand and shell, into which a considerable quantity of potsherds, animal bone, and ash was mixed. Frequently, layers of pure shell were encountered, but none of these extended completely through the mound. The base, consisting of gray sand, was not more than a foot above the salt water table. A few burials beneath the base lay below the level of high water. During the course of excavations 185 skeletons were removed. The general structure and appearance of the mound indicated that it had been built up gradually from village refuse as the occasion for more burials required. All of the skeletons were tightly flexed and, with the exception of one group of five which had evidently been placed on the mound at the same time and oriented in the same manner, there was little plan or order to the placing of the bodies.

There was a difference in level of 6 feet between the highest and the lowest burials. No objects of any sort had been placed with the bodies. The few artifacts which were removed had evidently intruded accidentally as part of the village refuse from which it was constructed. For this reason there was a large quantity of small plain sherds of a rather crude type of pottery. Decorations occurred in the form of incised patterns with the exception of a single sherd which contained a stamped design of concentric diamond-shaped figures.

A trench 25 feet in width was carried into the center of the smaller habitation mound. From the few simple artifacts recovered it is presumed that this mound was contemporaneous with the burial mound and was probably constructed by the same group. This mound contained much less sand than the burial mound, and thick layers of shell extended completely through from side to side. There were extensive ash deposits at the base, but these were sterile except for a small quantity of burned animal bone and shell. From this excavation a large amount of plain sand-tempered potsherds were found, as well as a quantity of animal bones. A single human tooth was also discovered. Only half a dozen decorated sherds were unearthed. All of these were decorated with angular designs in incised lines. One well-made shell celt, a lump of kaolin presumably intended for pottery making, a piece of red ocher, a broken bone awl, two or three abrading stones, and a conch-shell bowl complete the list of artifacts recovered from the trench.

The burial area was revealed by excavations to be roughly circular and about 40 feet in diameter. There were no indications of a mound

having been erected above the burials, although cultivation over the site might easily have removed traces of a low sand mound. The burials were comparatively superficial, the deepest skeleton being only 27 inches below the surface, while the majority were encountered at a depth of not more than 12 inches. Most of the burials lay beneath the water table, and it was necessary to remove them from the salt water, a feature which made it impossible to clear and expose the skeletons in the usual manner. However, the action of the salt water evidently preserved the bones, as they were in excellent condition except where they had been broken up by previous diggers. Forty-three skeletons were taken from this area, the bones of which were of almost rocklike hardness. They were not, however, mineralized. All of the burials were flexed in the same manner as those in the shell burial mound. The nature of the soil made it impossible to tell whether the burials were intrusive, but from all indications they were. Burials occurred in groups of from 3 to 6 individuals, each group being packed into a small area as though a hole had been dug and the bodies laid in closely to conserve space. Usually a quantity of shells were placed around each burial as though the pit had been partially lined with shell. As in the case of the shell mound it was evident that no artifacts had been intentionally placed with the burials. With the exception of a few sherds of undecorated pottery the only artifact found was a stemmed flint scraper. The exact relation of this burial area to the surrounding mounds could not be determined because of the absence of cultural material.

LITTLE MANATEE RIVER, MANATEE COUNTY

Mound no. 1.—This small mound was located northeast of the south branch of the Little Manatee River in section 12, township 33 S., range 20 E., about 16 miles northeast of Parrish.

The mound, constructed of white sand, was erected on high ground among a scrub growth of pine, wild plum, and oak trees. The visible portion of the mound measured 44 feet along the north-south axis and 38 feet east and west. Excavations revealed that the mound had been constructed over a saucerlike depression in which the first burials had been placed. On the south edge was a sump or depression measuring 12 feet in width and 22 feet in length, running east and west. At various times in the past 6 holes had been dug near the center, none more than 3 feet in depth. The mound was about 5 feet in height at the center, although the original height had undoubtedly been much reduced by erosion.

During the excavations 27 skeletons were encountered. All represented secondary burials, the bones being disarticulated and in a very poor state of preservation. Pottery was of the Safety Harbor type,

muck and sand-tempered black ware with buff surface. Shapes varied from shallow circular bowls to deep jars. Stamped decorations included a small quantity of check stamped patterns and one coarse complicated stamp representing concentric circles, on a large cooking jar. One bowl was decorated with a deeply incised interlocking scroll design composed of negative bands set off with coarse punctate areas. A characteristic feature is a notched lip, the notching being carried out sometimes directly on the top of the lip, sometimes on the outer edge of the rim and sometimes at the base of the neck band. One vessel with flat, vertical loop handles was recovered. No painted ware was found.

Six conch-shell bowls were found and two disk-shaped shell rings, each about $\frac{3}{4}$ inch in diameter. There were also two tortoise shell combs in a fair state of preservation and a circular object of copper 2 inches in diameter, probably an ear ornament, with a raised hemispherical boss in the center. Ten projectile points of white chert and brown flint were found. These were of 2 types, 5 with round bases and 5 with flat bases.

Objects of European manufacture were numerous. Three sherds of pottery retained portions of an olive-green glaze. Many thousands of small European glass beads of many different colors were recovered. In some instances they were found sufficiently undisturbed to indicate that they had been used as neck ornaments, bracelets, and bags. Unique types were one emerald green pentagonal drilled glass bead and a home-made bottle-green glass pendant, formed by melting a lump of glass and looping the tapered end so as to form a hole for suspension. This may have been the work of the Indians themselves. Two large drilled beads of quartz crystal were found, one about one-half inch in diameter with plane-cut facets and the other in the shape of an oblate spheroid with long spiral facets running from the two openings of the drilled hole. In addition to the copper ear ornament, which may have been of trade copper, metal objects included a conical bangle of sheet gold about $1\frac{1}{2}$ inches in length and 3 tubular silver beads $\frac{3}{4}$ to $1\frac{1}{4}$ inches in length. The absence of any indication of iron is worthy of comment.

Because of the abundance of glass beads the impression is created that this mound is rather late historic in period. The presence of a relatively abundant quantity of native pottery, shell bowls, and stone arrowheads together with the absence of iron would seem to offer evidence in the other direction. Tentative estimates place the building of the mound about the middle of the seventeenth century.

Mound no. 2.—This mound is located one-half mile south of the south fork of the Little Manatee River, on the property of T. W.

Parrish, who kindly consented to the work of excavation. As in the case of mound no. 1, the situation is on a high sand flat covered with a growth of short-leaf pines, ground oaks, and rosemary bushes. The circular mound measured 63 feet along the north-south axis and 65 feet along the east-west axis, with a height of approximately 6 feet. The highest section of the mound was toward the north, so that the north side sloped more steeply than the other sides.

This mound proved exceptionally interesting, as it contained the lower portions of the walls of what had evidently once been a mortuary temple (pl. 3, fig. 1). The posts comprising the supports were from 5 to 10 inches in diameter and owed their partial preservation to the fact that they had been intentionally charred before being planted in the sand (pl. 3, fig. 1). The charcoal shell of each post remained. The posts were planted 4 to 4½ feet deep and set about 5 inches apart. Since the posts followed the contour of the mound, they indicated that the mound had been completed before the structure was erected. The bottoms of some of the posts were pointed, and others had been squared off. The plan was in the shape of a trapezium, the sides averaging slightly more than 25 feet in length. The southeast corner of the structure had been reinforced with an extra row of posts placed between and just inside of the primary posts. This reinforced angle extended 7 feet on one side and 6 feet on the other. Within was a thick deposit of charcoal, ashes, and burned human bone. Inside the enclosure were found 32 secondary cremated burials and 2 uncremated burials of small children. These bodies had apparently been cremated in the reinforced angle of the structure and the remains buried while still hot in the sand floor of the building. In the center of the floor was a large, deep charcoal pit containing numerous burials and most of the burnt offerings that were recovered. Outside the walls of the structure were 5 secondary and 2 direct cremations. In the case of the latter, pits had been dug and small wood placed on the bottom of the graves. The body in each case had then been placed on the back with the head to the south, the knees slightly flexed. The body was then covered with logs and sticks placed lengthwise in the grave and fired. When the pyre had been reduced to glowing embers, the graves had been filled in, as the logs, completely reduced to charcoal, were all in place.

Pottery was not abundant. A very interesting owl-effigy water bottle of a familiar lower Mississippi type was taken from the central part of the mound during a previous excavation. One fragmentary muck ware cooking bowl, fiber-tempered, with an incised interlocking spiral design, was found, and also a few scattered fragments of undecorated ware. One small shell hoe and three conch-shell bowls

were found. With one burial were found two perforated shell rings $\frac{3}{4}$ inch in diameter. Three small white arrowheads with flat bases, one polished white chalcedony pendant, and a drilled cylinder about $1\frac{3}{4}$ inches long by $\frac{1}{3}$ inch in diameter of a gray fine-grained stone were recovered. At one place was found a deposit of six ropes of rosin which had probably been used as torches or were possibly for use in connection with the cremations. With one of the direct cremations was a charred piece of wood with a carved spiral design on it, and in the central pit were found some very interesting charred fragments of braided and woven hair. A tortoise-shell comb was recovered with one of the burials. Objects of European origin consisted of a small brass ornament shaped somewhat like a fleur-de-lis and 3 small glass beads, 2 blue and 1 white.

This mound is very puzzling. It is the first mound in Florida to produce definitely cremated bodies. The presence of a few objects of European origin show it to be post-Columbian.

Mound no. 3.—This mound is located in the northwest quarter of section 27, township 33 S., range 19 E., on the north bank of Gamble Creek.

The mound proper is circular in shape, 68 feet in diameter, and 7 feet in height. A horseshoe-shaped depression 17 feet in width and 2 feet in depth encircles the mound about its southern periphery, the two arms then converging slightly to the north for 100 yards, tapering off into the flat before converging. Exactly adjoining this depression, and hence of the same shape, is a sand ridge 30 feet wide and 3 feet high. Seventy-five yards in a southeasterly direction lie two smaller circular mounds.

During the course of excavations 212 recognizable burials were encountered. These were all secondary bundle burials with the exception of one intrusive cremated burial, all in a very poor state of preservation. The long bones were placed parallel in a neat bundle almost all pointing east and west, although a very few pointed north and south. In every instance the skull was placed a little above the bundle, at the west end when the bundle lay east and west and at the south end when it lay north and south. Frequently, charcoal was found above the burials as though a fire had been made over the grave.

Pottery in this mound was fairly abundant and appeared to be of a somewhat degenerate Weedon Island type. Shapes varied from pear-shaped bottles to shallow bowls, with large deep jars having slightly constricted necks and flaring rims (pl. 2, figs. 1 and 2). One large globular bowl, with a fugitive red slip, was found. All pots had a small circular hole in the bottom. Some of the vessels had evidently been broken intentionally. Stamped ware included both

a check and complicated stamp. Incised designs were usually combined with tatooing, and interlocking scrolls were the most typical pattern. Notched lips were common on the deep vessels as were flat lips on the shallow bowls. One large sherd of typical Weedon Island ware was discovered. One pear-shaped vessel was decorated with an incised eagle feather design. All the ware is untempered and is of two types, muck ware and clay ware. The first is made of black muck which ranges from buff to brick red in color when fired. Upon being broken the inner part of the ware can be seen to retain its black color. This ware has a hardness of 2.5 and is smooth and velvety in texture, being free from grit, and is very light in weight. Microscopic examination discloses the substance of the ware to be a mass of carbonized organic material.

The clay pottery is made of a white clay which contains naturally a certain amount of grit. Two large lumps of this clay were found in the mound, still retaining the finger marks of the hands that had moulded them. This ware also has a hardness of 2.5 but is considerably heavier than the muck ware.

Fourteen conch shell bowls were recovered in the mound. Most of these had a hole in the bottom as did the pottery.

Six stemmed knives and arrowheads were recovered, and two with concave bases. One large triangular chipped blade may have been either an axe or a knife. There were about a dozen turtle-back scrapers and one small triangular arrowhead. Throughout the mound were scattered many flint spalls. With one burial were three chipped spherical flint cores, each about the size of a baseball. Four sandstone abrading stones complete the list of stone material.

Three lumps of red ochre mixed with sand were found with burials, while frequently the sand around the skulls of the bundle burials would be reddened with ochre.

European material consisted of a few small glass beads, mostly blue or white in color, and a short blunt iron chisel.

With the cremated burial previously mentioned, were found five small glass beads, one of which was melted, two calcined stemmed flint arrowheads and several unidentified pieces of iron which are probably parts of a gun. These iron pieces were clustered around a sandstone abrading stone, to which they adhered.

This mound appears to be older than mounds nos. 1 and 2. European material was scarce, and that which occurred was superficial, except for the articles accompanying the cremated burial. The sherd of Weedon Island pottery is of a type heretofore found only in pre-Columbian mounds. The rest of the pottery, although related to this ware, is not typical Weedon Island. My impression is that this mound is very early post-Spanish.

Mound No. 4.—This mound is located in the northwest quarter of section 23, township 33 S., range 21 E., about 400 yards north of the south fork of the Little Manatee River. The mound is composed of a rather fine buff-colored sand, and is 80 feet in diameter and 7 feet high.

The burials throughout the mound were so badly decomposed that many were no longer recognizable. However, 89 burials were definitely identified. The form of burial was difficult to ascertain, but it is certain that the interments were secondary. In some instances the bones were burned, but none appeared to be true cremations. The sand around the burials was stained with red ochre.

Artifacts were very scarce. Pottery consisted of not more than a dozen sherds, including one nearly complete small check stamped bowl. Another small bowl of good quality ware was decorated with closely spaced vertical parallel incised lines. Two large fragments of a very thick and heavy vessel of crude cooking ware were found; these are the thickest pottery fragments I have ever seen in Florida. The ware is of the usual two types of this region, untempered muck ware and clay ware.

Stone objects consisted of a highly polished plummet of a fine-grained gray stone and arrowheads. Fragments of conch shell, probably parts of shell bowls, were found occasionally throughout the mound. One shark tooth was found with a burial.

This mound appears to be the oldest of the group excavated on the south fork of the Little Manatee River. There were no objects of European manufacture present, and although the state of preservation of skeletal material is not a certain criterion of age, it is worthy of mention that the skeletal material here was so disintegrated as to have almost disappeared.

Because of the scarcity of pottery, it is difficult to establish the cultural relationship of the site. However, I should estimate that the mound was erected during the late fifteenth century.

ENGLEWOOD MOUND, SARASOTA COUNTY

This mound is located on the mainland about 150 yards from the east shore of Lemon Bay and about one-half mile south of the town of Englewood. It was constructed entirely of sand and was 110 feet in diameter and 13 feet high. Considerable pitting had been done on the top, so that the original height was probably somewhat greater.

Near the site are two deep depressions from which the sand comprising it had been obtained. One of these lies just to the north of the mound and the other near its eastern margin. Complete excavation of the site revealed that the visible portion had been super-

imposed on a small, low primary mound, which in turn covered an extensive burial pit. This primary mound was about 5 feet in height above the old soil line and was approximately 50 feet in diameter. It was constructed of brownish-yellow sand contrasting with the lighter yellow sand of the secondary mound. The surface of the primary mound was coated with a layer of pure white sand, no doubt taken from a 10-inch layer of the same material which lay just below the old soil line. A layer of sand well mixed with red ocher lay immediately over the burials throughout the pit. There was one pit outside of the large burial pit which proved to be sterile.

During the course of excavations numerous potsherds were recovered. Sherds were scattered throughout both of the mound structures, and occasional small caches of pots were encountered in the secondary mound. All of the vessels had a small round hole in the bottom (pl. 3, fig. 2). Potsherds were particularly numerous throughout the base of the mound. The ware is similar in type to that found at Safety Harbor and consists of both muck and clay vessels, both of which are untempered. Designs consist of both incised and stamped decorations, with punctate areas setting off negative bands as a common motif. Check stamped ware was particularly abundant. Incised decorations consisted of straight lines rather than curvilinear. Punctate markings enclosed in a joined triangular pattern was a common type of decoration. Rim decorations on otherwise plain pots were not uncommon. Scalloping, raised flanges, and single incised border lines were commonly used as rim ornaments. One vertical loop handle was found.

Conch shells were scattered throughout both mound structures, being most numerous just above the old soil line. A number of conch-shell bowls were found, these having been "killed" in the same manner as the pottery vessels. A few conch-shell hoes were also found. Stone artifacts were almost entirely absent. Two flint cores were recovered, and occasional flint chips were scattered throughout the secondary mound.

The skeletal material was in a very poor state of preservation. Although 300 burials were encountered in the mound, there were less than a dozen sufficiently well preserved to permit of satisfactory measurements being taken. In spite of a new method of spraying with preservatives, comparatively little of the skeletal material could be saved. The bones indicate that the builders of the mound were a short but stocky people. Secondary bundle burials were the predominant burial type. All of the interments in the large burial pit were secondary, as were all but 11 of the burials in the mound proper. These 11 were tightly flexed. A great deal of red ocher had been placed with the bodies in the burial pit, and slight indications of it were found in proximity to burials throughout the sec-

ondary mound. One hundred and twenty-five burials had been made in the pit, all of these being at a uniform depth. On the other hand the burials throughout the secondary mound were scattered at all levels in the mound structure.

The general excellence of the pottery and the complete absence of artifacts of European manufacture indicate that the mound is prehistoric. An interesting feature is the fact that this is the southernmost location at which high-grade pottery has been found of the type common on the northwest coast of Florida. Although there were clearly two separate structures within the mound, no difference could be noted in the types of pottery found in each.

CANAVERAL PENINSULA, BREVARD COUNTY

Historical summary.—This part of Florida when first discovered and later explored by the Spanish was inhabited by a tribe of Indians known as the Surruque or Curruque, who were of the Timucuan family and were the southernmost band of this stock on the Florida east coast. Menendez, the founder of St. Augustine, held a council in 1566 at or near Cape Canaveral, which was attended by no less than 1,500 of these Indians. In 1598 the Spanish governor sent a punitive expedition against the Surruque because of the murder of Spanish sailors cast away on this coast. Whether the accusation was true or false, 60 of the Surruque were killed and 54 were taken into slavery. Between 1613 and 1617 a severe epidemic raged among the Timucuan tribes, reducing the population by nearly one-half, and it is safe to assume that the Surruque too suffered greatly. The Surruque joined in the uprising of 1656 against the Spanish Friars, which was put down by the authorities with great severity so that they again suffered heavy casualties. Following this we hear of another plague in 1672, and the mission records show a dreadful mortality among the tribes of this region. In 1704 the Surruque were involved in the fighting between the Spanish troops on the one hand and the English, aided by their Creek allies, on the other, and it appears that they suffered about equally from both. The last mention of any of the Timucuan tribes of this region appears in 1728, when their number is described as reduced to a few miserable villages. After this date they are no longer mentioned in the early records. The recorded history of the Surruque left us by the early explorers of Florida is a brief catalog of repeated disasters ending with their final disappearance slightly more than 100 years after their first contact with Europeans. It was for the purpose of supplementing these scanty historical records that excavation was undertaken in this territory. The shell heaps where the Surruque lived were once abundant but are gradually being destroyed for road-

building material, and the sand mounds erected nearby for the burial of their dead are also being molested.

Two sites were excavated: The first, consisting of five small sand mounds, was 1 mile south of Artesia; the second, a single sand mound, was 4 miles north of this town. The excavation of the largest mound at site no. 1 (mound A) revealed a small, low heap of sand on the natural surface of the ground. Upon this had been placed a thin but uniform layer of oyster shells. On top of this had been spread another layer of sand which contained burials.

The burials were on the whole in a good state of preservation, although none had been buried more than a foot below the surface. They had been oriented with some care, for the majority were placed with the head toward the apex of the mound, like the spokes on a wheel. Although oriented similarly, the skeletons were not always lying in the same position. The majority were fully extended, lying on the back. Others were slightly flexed and had been buried on either the right or the left side. A few were placed in other positions but these were exceptions. The burials may be classified under three headings: Complete undisturbed skeletons; incomplete skeletons (part of the body missing), and disassociated bones. The complete skeletons form an excellent series of 96 specimens, 35 adult males, 42 adult females, 7 adults whose sex could not be determined in the field, and 12 infants. There were as many more individuals represented by disturbed and fragmentary skeletons. These were most prevalent near the apex of the mound where tree roots had disturbed them. From field observations it would appear that the Surruque were a tall people of robust physique. The skulls were large, undeformed, and uncommonly thick, and the long bones were heavy and massive.

Either the Surruque were limited in material possessions or they were not accustomed to bury many mortuary objects with their dead, for very little material was found in their burial mounds. No whole pieces of pottery were found. The sherds showed that two varieties of ware were common, one a heavy black plain variety, the other similar but decorated with a crude check stamped design. The artifacts consisted of plummets of stone or conch shell, long bone hairpins decorated with curvilinear and rectilinear designs, a bone whistle, bone and shell beads, and small bone pendants. In this mound objects of brass and iron as well as glass beads indicated contact with the Europeans and dated the mound as post-Columbian.

The fauna, like the potsherds, was similar in all the mounds excavated. Shellfish were abundant and appear to have formed the principal article of diet. They included the common Coquina clam, the oyster, and several varieties of conch and scollop. The animal bones

represented deer, bear, raccoon, and opossum. Fish bones representing many varieties, as well as the loggerhead and box turtle, showed that these were common articles of diet.

Mound B was located 130 feet north of A and was covered with a dense growth of small trees (pl. 3, fig. 3). This mound was similar in construction, although all levels proved sterile until the apex of the mound had been reached. In a radius of $6\frac{1}{2}$ feet at the very apex of the mound was a sort of burial pit in which the skeletons had been placed without any apparent plan. Many of them had been completely disarticulated prior to interment. It is estimated that they represented about 20 individuals. Only two burials were found outside of this restricted area; they were located 1 foot 8 inches to the north of the pit. Both had been buried tightly flexed lying on the side and oriented with the feet toward the center of the mound. All the bones found in this mound were in a poor state of preservation. The potsherds, artifacts, and fauna were in every way similar to those found in mound A, but there were no metals or other evidences of European contact.

Mound C was 130 feet west of mound B. A few potsherds of the same general type as previously described were found, but otherwise the mound proved sterile.

Mound D was 41 feet 6 inches west of mound A in an abandoned orange grove. When this was opened its construction proved to be of the simplest kind. It was merely a low mound of clear sand covered over with a thick layer of clam and oyster shells. All burials were found placed a few inches from the surface in the southern and western periphery of the mound. The remainder of the mound was entirely sterile. Of the 16 burials recovered in a good state of preservation, 6 were adult males, 3 adult females, 2 adults of doubtful sex, and 5 were infants. The skeletons were in the same positions as in mound A and were oriented according to the same general plan. The potsherds, artifacts, and fauna were the same as have been already noted, but the presence of glass beads with some of the infant burials indicated that the mound was of post-Columbian origin.

Site 2, mound A, was 80 feet in its greatest diameter and 13 feet high. It was covered with a heavy growth of scrub and large trees and lay adjacent to the remains of the shell heap. When it was trenched, its construction proved a matter of some complexity for it had apparently served a variety of purposes since its erection. The lowest level was a horizontal habitation stratum extending far beyond the limits of the mound proper, and in it were found charcoal, food bones, and shells, but no burials. Upon this had been erected a sand mound which contained burials. Above this was a

thick laminated deposit which contained numerous burials as well as charcoal, potsherds, and shells. The burials from the superficial and the deep deposits have been plotted separately on the plans of this mound, but otherwise there is nothing to distinguish them.

The state of preservation of these skeletons was very poor. The bones were all found to have been badly crushed by earth pressure as well as being in an advanced state of decomposition. They had been oriented with the head toward the center of the mound but their individual positions were not uniform. Fifty-two skeletons were recovered, and of these 22 were adult males, 20 were adult females, 8 were adults who could not be accurately sexed, and 1 was a child. As nearly as could be determined from their crushed condition, they were similar to those excavated in site 1.

The material culture and the fauna were identical with those already described, but there were no articles of European manufacture.

ORMOND MOUND, VOLUSIA COUNTY

This was a small sand mound 60 feet in diameter and 6 feet high located on the eastern edge of the Halifax River a mile south of Ormond bridge in the city of Ormond Beach. Several pits had been sunk into the mound by previous diggers, but damage to the mound structure had not been great. Complete excavation revealed that it had been erected upon a layer of earlier rich, black village site refuse. Above this black stratum was a layer of ash-gray sand identical in appearance with the surface soil existing in the vicinity at present, indicating that considerable time had elapsed between the abandonment of the village site and the construction of the mound.

When excavations had progressed through about one-third of the diameter of the mound, burials were encountered on the lower level just below the village site layer. These burials were extended on the back and were arranged in two concentric circles in such a manner that the head of one burial approached within a foot or two of the feet of the next. In several instances these burials were in pairs. Most of the bones were badly crushed. Apparently the inhabitants of the village site buried their dead in shallow pits, barely covering the bodies. The skeletons then became crushed, either as a result of the burial place being lived upon or by the weight of the mound later erected above the burials.

In the mound itself the burials were also extended in the same manner, but there was no semblance of regularity in the way they had been placed. They occurred at all levels, lying in all directions. In certain places they were bunched together as though buried at the same time, and in other sections of the mound were areas of comparative sterility.

The few artifacts found with burials accompanied those of the lower level, with the exception of a bird skull found with a burial in the mound proper. Beneath the mound were a number of fire pits. These were sunk from the original soil level through a depth of about 3 feet. They varied in width from 1 to 3 feet at the bottom and from 4 to 6 feet at the top. The pits were easily distinguishable by their fill of black earth, charcoal, and burned shell. The bottoms were marked by a zone of fire-reddened sand which had been subjected to intense heat, and a layer consisting of a rocklike formation on the bottom composed of fused sand, ash, and bits of shell.

Occasional pockets of shell occurred throughout the mound. The most extensive of these was a layer of coquina shell about 8 inches thick which followed the contour of the northern half of the mound.

In spite of its relatively small size the mound produced considerably more pottery than is usual in this section of Florida. It is a muck ware, very light in weight, and grades in color from buff to black. Decoration is usually lacking, but where it occurs it consists of stamped or cord-marked patterns. A few vessels were covered with a fugitive red slip. Three of the vessels restored in the field are of the basin type. One is a small, squat water bottle, and two are bowl-shaped with slightly incurving rims. These latter have a round hole in the bottom. One large pottery pipe of elbow form was found accompanying a burial. Three bone awls, three stone and shell "plummets", and five chert projectile points complete the list of artifacts discovered. All of the "plummets" were found on the breasts of the burials which they accompanied, indicating that they had been worn as ornaments. No artifacts of European manufacture were found either in the mound or in the village layer. Although it is not possible in view of the fragmentary state of our archeological knowledge of this section to name with certainty the former occupants of this site, in all probability they were one of the Timucua tribes of the Fresh Water Province of the Spaniards, possibly the Mayaca.

GEORGIA

MACON, BIBB COUNTY

The region around the city of Macon, Ga., is rich in vestiges of aboriginal occupancy, including several village sites marked by distinct house rings. Intensive work was undertaken in two neighboring groups of mounds, the Macon group consisting of about half a dozen, and the Lamar group, which consists of two large and interesting mounds, around which is a village site. Both of these groups are on the east side of Ocmulgee River, the first mentioned

being in the outskirts of the city of Macon, the second about 3 miles below.

The eastern mound of the Lamar group is interesting because of a spiral counterclockwise ascent which extends around it from base to summit. This mound was cleared but not explored, the excavations at Lamar being confined to the west mound, which is roughly quadrilateral in shape, and to the village site. On the east side of the west mound a section was made which demonstrated a change in pottery types between the lower and upper levels. The house plans in the village proved to be rectangular in form.

Excavations were conducted on all of the principal mounds of the Macon group. A deep shaft was sunk from the top of mound A about half-way to the bottom. This mound, which is 45 feet in height, is one of the highest in the United States, and its impressiveness is enhanced by the fact of its being erected on the end of a high ridge which falls away steeply toward the river and which places the summit of the mound 105 feet above the river level. A section was made on one side of mound B, which is closely connected with mound A by a section of the ridge on which mound A is constructed.

Much more extensive work was done on mound C and on a later village site along its eastern margin. Numerous burials, the bones usually in an advanced state of decay, were found, some accompanied by beads and one with copper ornaments. A complete section of the northern side of the mound was made (pl. 4, fig. 1). This section had already been partly exposed by a railway cut. At least five successive construction levels were disclosed, the top of the mound in each case having been sealed with either slate-colored or vivid red clay. At the very bottom of the mound, head to the west, lay a skeleton on wooden crosspieces flanked on each side by uprights of the same material. About the neck were many disk-shaped shell beads. The original mound structure was evidently directly related to this particular burial.

Mound D, while not as imposing in appearance as any of the foregoing, proved to be in many ways the most interesting and important. This mound consisted of two sections separated by a depression. The smaller section when excavated proved to be the ruins of a circular council house, the red clay roof of which had fortunately buried the floor sufficiently deep to protect it from the white man's plow. Clay seats for 50 people encircle the wall of the structure. In front of each seat is a depression, evidently constructed to serve as a receptacle. All but three of the seats are separated from one another by clay ridges. The three exceptions, evidently intended for the leading men, are upon a raised dais or alter,

also of baked clay, worked into the effigy of an eagle. This altar is directly opposite the entrance. The seats of the chiefs were upon the back of this effigy. In front of them, toward the center of the building, was the eagle's head turned in profile to the southwest and made with an eye ornament similar to that seen on various copper effigies from the mounds and in certain incised pottery from the Southeast. In the center of the floor was a modeled fireplace, built up carefully of clay, and around this were four holes for the main roof supports. The outer ends of the roof timbers appear to have rested directly on the clay wall. The entrance, which was toward the southeast, was also worked in clay and consisted of a narrow tunnel passage with offsets on each side of the entrance, probably for the purpose of protecting the men seated near the entrance from cold drafts (pl. 5, figs. 1 and 2). Upon completion of the excavation of the council house, a tile wall with a temporary roof was erected to protect it from injury by man and the elements.

Exploration of the remainder of mound D revealed the outlines of several smaller rectangular structures evidently built at different periods. Most interesting of the discoveries was the remains of a cornfield which antedated all of these structures but one. The striking thing about this is the fact that the corn is shown to have been planted in rows instead of in hills as was the Indian method farther north and which heretofore was supposed to have been the general Indian usage (pl. 4, fig. 2). So well is this field preserved that even the paths across the rows can be clearly traced. Later excavations revealed several pits east of the council house, and although the exact significance is still in doubt, it is thought that they are the foundations of rectangular pit houses. None of the historic Indian towns of any importance was located on Ocmulgee River after 1715, and historic evidence as well as that furnished by the present explorations indicates that the last villages were relatively insignificant.

European objects have been found only in the late village site on the east side of mound C of the Macon group and in some surface gleanings from Lamar. The De Soto narratives seem to indicate that the Macon and Lamar sites were but sparsely occupied, if at all, in 1540 when the Spanish explorers passed through Georgia. This means that the great mounds were wholly pre-Columbian in origin. Nevertheless, the Lamar mounds suggest Creek methods of construction, and for this reason and from the internal evidence of the potsherds it seems quite likely that this group is of later origin than the Macon group. Mound D containing the council house and the cornfield appears to be among the oldest of these structures. The council house contains structural features highly reminiscent of the northern Plains earth lodge and also of the Pueblo kiva. More actual work

has been conducted on the Macon group than on any other group in the history of systematic archeology in the Southeast, and the final results of the work should furnish us with keys to many of the general southeastern problems.

NORTH CAROLINA

PEACHTREE MOUND AND VILLAGE SITE

To recover at least a part of the prehistory of southwestern North Carolina, an important Indian mound and village site in the Hiwassee River Valley, near the mouth of Peachtree Creek, was selected for excavation. This selection was made upon the recommendation of Dr. John R. Swanton, ethnologist in the Bureau of American Ethnology, who regards the location as, in all probability, that of Guasili, visited by Hernando De Soto and his soldiers in the summer of 1540.

The mound, 215 feet long, 180 feet wide, and $10\frac{1}{2}$ feet high, was built above a 2-foot stratum of black loam, in which were found burial pits, post holes, and much village-site debris. Originally it was a truncated pyramid, an artificial elevation commonly used by various southeastern Indian tribes as supports for temples or chiefs' houses. Within 4 feet of the top, three distinct hard-clay floors were superimposed, indicating that when the mound had reached a certain height the top was leveled off and a wooden structure with a clay floor was built. After its destruction by fire or other agencies a second structure was superimposed. This occurred at least three times.

Except for important features in the mound very few artifacts or burials were placed in the mound proper. However, Indians buried in pits dug into the mound surface were associated with articles of European origin, such as glass beads, lead bullets, and broken spurs, indicating contact with the white man. Most of the skeletal material was poorly preserved.

The most important feature in the mound proper was the remains of a structure 25 feet square and probably 7 feet high. Excavation revealed a hard thin floor extending beyond the walls, which may have constituted the floor of a much larger structure. The sides of the building consisted of piles of stones, which served as a foundation to support vertical posts (pl. 6, fig. 1). Four large post holes were found, one at each corner, remnants of the main roof supports. The stone walls rested on the clay floor, but the holes extended beneath it. Residue of the pole and brush roof lay in the center of the various compartments. There existed at least six partitions or rooms along the stone walls (pl. 6, fig. 2). These

partitions were made with yellow clay encircling sticks 1 to 2 inches in diameter. Such a structure could have been used as a ceremonial sweat lodge or men's clubhouse.

Excavations in the surrounding village site and below the base of the mound indicate that the mound was superimposed on the village site. Numerous burials were obtained from this habitation area. The rich nature of the soil was not conducive to preservation. The bodies were flexed—knees drawn to the chest—soon after death, and placed in small pits, on the left side, with one or both hands drawn to the face. The most important burial was found beneath the mound floor, fairly well preserved (pl. 7, fig. 1). Associated with it were two copper ear ornaments and cane matting. Some intrusive burials were made in stone-lined graves (pl. 7, fig. 2).

Observations regarding artifacts, based on the fragmentary specimens recovered from both the mound and the village site, were as follows: Slate was the most commonly used stone for fashioning gaming stones, discoidals, and small celts. Vessels were carved from steatite. Mortars, axes, projectile points, and smoking pipes were made from a variety of materials. Animal bones were cut and polished for making awls and fish hooks. Various ornaments, such as beads and pendants, were carved from unio and conch shells. Small pieces of copper were fashioned into ornaments.

The smoking pipes were small, usually made from a dark, close-grained igneous rock. They were of the stemmed variety, bowls showing considerable variation in shape, size, and design. Small effigies occasionally occurred on the bowls. The baked clay pipes show a wide variety of form and incised designs. A few examples of the flaring trumpet-shaped bowls are comparable to those from Etowah, Macon, and the Nacoochee mounds in Georgia.

Only a very general description can be made of the various potsherds until a more careful study has been made. Observations in the field justified conclusions that types above the mound floor level differed from those below the base. The sherds in the mound were decorated on the outside with a wide variety of stamped designs. They are tempered with coarse grit. Color varies from black through various shades of gray and tan to a dull brownish red; the inside shows construction and smoothing marks, yet is fairly smooth without any attempt at polish; the ware breaks irregularly, leaving a rough, lumpy edge. About half the rim sherds have thumb-nail marks or are incised; the rest are plain.

The various random samplings of sherds from below the mound level show variations from those in the mound. In one 10-foot square the sherds show a larger number painted red; the temper is not as coarse; the interior and exterior surfaces show evidence of

more polish. An occasional shell-tempered sherd was found. From another 10-foot square below mound level a decided difference was noticeable. Twenty-five percent are painted red; many are undecorated; decorated sherds are either stamped or incised; 40 percent were shell-tempered. In many cases the shells disintegrated or leached out from the exposed surfaces, leaving a porous or cell-like surface. Strap and loop handles occurred more frequently below the mound, whereas lug and flange handles were found in the mound. The decorative stamp patterns are comparable to types from the Etowah and Nacoochee mounds in northern Georgia.

Positive conclusions or definite affiliations cannot be stated here. Nevertheless, the following recapitulation may be made: The mound was built primarily for ceremonial rather than for burial purposes as indicated by its several superimposed floors, large stone and wooden structures, and the lack of burials. The potsherds and smoking pipes belong to the general northern Georgia area, exemplified by Etowah and Nacoochee mounds. At least 2 and perhaps 3 culture levels were obvious; the village site beneath the mound, the mound itself, and the surface of the mound, which revealed contact with Europeans. The first Europeans to visit this site, in the opinion of Dr. J. R. Swanton, were De Soto and his army in the year 1540. The town at this place is said to have contained 600 wooden houses—probably an exaggeration—and was the capital of a province where the hungry explorers were given a hearty welcome. One of De Soto's men informed the chronicler Garcilaso de la Vega that "The lord who bore the name of the province left the capital half a league to meet the Spaniards, accompanied by 500 of the principal persons of the country, very gayly dressed after their fashion. His lodge was upon a mound with a terrace round it, where six men could promenade abreast." Even though no artifacts were recovered that could be identified as belonging to these first European explorers, nevertheless Dr. Swanton, who has devoted considerable time to the study of De Soto's route, feels satisfied that this is the site of Guasili.

TENNESSEE

THE SHILOH MOUND GROUP, HARDIN COUNTY

The Shiloh site near Pittsburg Landing, is situated on a high bluff above the west bank of the Tennessee River and lies between two deep ravines, through which flow tributary branches of the main stream. Outstanding features consist of 7 large mounds, 6 domiciliary and 1 burial, and numerous low elevations which mark the places where dwellings once stood. To the west of the area of occupation is an embankment, extending across the neck of the bluff from

one ravine to the other. This low ridge of earth indicates the former existence of a palisade which protected the community at that side.

The first excavations consisted of a series of trenches dug at regular intervals in the area surrounding and lying between the main mounds (pl. 8, fig. 1). These trenches revealed a number of interesting things, among them the remains of 30 houses, a temple, and numerous refuse deposits.

The houses were found to have been round in outline, with walls of wattle and daub construction. This was evidenced by the fact that there were large quantities of burned clay bearing the impression of poles and cane and even, in some cases, small sections of cane walls in the debris removed from the floors of a number of houses which had been destroyed by fire. The wall of each house was supported by a series of heavy posts, 2 to 3 inches in diameter, placed at intervals of approximately 4 feet around the periphery. The spaces between these upright timbers were filled by panels of cane strips. The latter, averaging $\frac{1}{2}$ inch in width and $\frac{3}{16}$ inch thick, were placed side by side in vertical position. In most cases they touched along their edges. The vertical strips were reinforced by a series of horizontal canes spaced approximately 1 foot apart and extending from post to post. The horizontal and vertical pieces were not interwoven, and there was nothing to show how the horizontal ones were held in place, although indications were that they had been on the outside of the wall. The canes were covered with a thick coating of mud plaster. Where indications of an entry or doorway were present they were invariably on the east to southeast side. Two of the structures had had a passageway leading to the doorway. The only interior feature noted was that of a shallow, circular fire basin in the center of the hard-packed floor. A few examples had a raised rim of mud plaster, but most of them were merely depressions in the floor. The average house was 16 feet in diameter and, judging from burned posts in a number of those uncovered, the walls were approximately 8 feet high. The floor was on or slightly below the ground level. Where depressed, this was no doubt due to constant sweeping of the area. There was no indication of a pit dwelling. The mounds covering the sites of many of these structures were merely the result of debris accumulating around the fallen walls and roofs. Practically every small mound had a depression near the center. This feature was due in part, no doubt, to the fire basin, but was sufficiently pronounced to suggest that there was an opening in the roof above the fireplace.

The remains of the structure tentatively called a temple were so designated because the building had been much larger than any of

the others and in addition it had been oval in form. The ends were curved and the sides straight. The main construction had been wattle and daub with supporting posts and intervening canes. Both the heavy posts and the canes had been set in a narrow trench, a feature not present in the circular houses. A short entrance passage had been placed at the east side. From the south end of the structure a palisade had extended some distance to the base of one of the major mounds. An interesting fact connected with this building was that an older structure of similar form and size had occupied almost the identical spot. The outline of the older or first structure was traced below the floor and surrounding outside occupation level of the later building. There was no suggestion of any appreciable time interval between the two as there were only a few inches of fill between the two floor levels. This fill did not have the appearance of gradual accumulation—rather that of material deposited all at one time.

The refuse deposits were in no case either extensive or deep. The material comprising the middens was largely mussel shells, animal and fish bones, charcoal, ashes, potsherds, stone chips, and stone spalls. All of the refuse mounds were completely covered by recent accumulations of earth and there was no evidence of their existence on the present surface.

The embankment extending across the ridge was trenched in several places for a distance of several hundred feet, and the molds made in the earth by the posts of the palisade were clearly in evidence. At several points along the palisade were indications of bastions or watchtowers. At one place the embankment was broken by a small ravine. Since the remains of the palisade extended to the edges of the gully on each side but did not go down across it, the ravine may have been eroded after the Indian occupation. The break occurred at a section of the palisade which would have rendered the whole feature practically useless from the standpoint of protection had it been present at the time the site was inhabited.

The burial mound was sectioned, a large block of earth being removed from its center and also along one side (pl. 8, fig. 2). Thirty interments were uncovered during this operation. The latter in most cases gave clear-cut evidence that they had been placed in the mound subsequent to its erection. All of these burials were in the flexed position, the legs bent and the knees drawn up. There was considerable variation in the positions of the hands and arms. In a majority of cases the head was toward the east. On the ground level near the center of the mound there originally was a log- or timber-covered burial pit which apparently had contained four bodies. It was impossible to obtain correct data on this feature be-

cause park authorities dug into the mound some 35 years ago and removed part of the timbers and most of the bones. Indications were, however, that the pit had been approximately 14 feet long and 33 inches wide, and the bones were 1 foot below the top log. Heavy cross timbers of cyprus, approximately 8 inches in diameter, had supported heavy slabs of cypress or chestnut timber extending the long way of the pit. It was from this tomb that the large red stone effigy pipe of a squatting Indian which C. B. Moore figured and described in his report on Tennessee is reputed to have come. There is some question as to whether this specimen actually came from this site.

Two of the domiciliary mounds were trenched to verify their identification as such. Interesting information was obtained as to the manner in which they were erected, and it was noted that one of them had been placed over the remains of a circular wattle and daub dwelling. No specimens were found in them, and no traces of buildings were noted on their tops. These mounds are roughly rectangular in form and have flat tops; the burial mound was oval and rounded on top. There were no indications of ramps or approaches leading to the tops of the mounds. The other four mounds were not touched.

Specimens recovered from the excavations consist of several restorable pieces of pottery; large quantities of potsherds; stone implements, such as knife blades, drills, spearheads and arrowheads, celts, and scrapers; bone implements; shell ornaments; and plaques of mica. No copper was found, although objects made from it have been reported from other sites in the immediate vicinity. The pottery shows an approximately even division between that with shell-tempering and a ware in which grit was used as a binder. Stratification indicates that grit-tempering was the older form, although it continued in use after the appearance of the shell. There was a great quantity of smooth-surfaced ware; an appreciable amount of cord-marked pottery, most of which was grit-tempered; some with basket impressions; scarified surfaces of the type associated with the Fort Ancient Culture in Ohio; and some paddle-marked ware. A few fragments of the Arkansas type of red ware were found. There was no indication either of effigy vessels or of containers with supplemental effigy features. Numerous fragments from large "salt pan" vessels are present in the collection of potsherds. These are of both the smooth-surfaced and textile-marked varieties. One of the main features of the pottery specimens is the large number and variety of handles and handle types present. Practically all common forms of Mississippi Valley spearheads and arrowheads, knife blades, and scrapers are in the collec-

tion. Numerous examples of the small, triangular Cherokee point were found on the surface, but none came from the trenches or refuse deposits. The celts are of two types, a small polished implement and a larger chipped form. Tentatively, it may be said that the material is very suggestive of the Mississippi Basin culture. Some aspects indicate a relationship to M. R. Harrington's middle level on the upper Tennessee, the type preceding the Cherokee.

Above and below the main mound area, on both sides of the river, within a radius of 2 miles, are numerous village sites and small burial mounds. The village sites give evidence of a comparatively lengthy occupation, which is in contrast to the general indications at the main mound cluster. Moreover, the various villages were for the most part located on low ground which is subject to flooding by the river. Because of this condition it is thought possible that the site on the bluffs may represent both a refuge spot to which the Indians retired during times of high water and the religious center of the region which was placed beyond the reach of floods. A small group of priests and their attendants may have occupied the large center continuously, whereas the larger groups were present only in times of stress or for ceremonial observances.

CALIFORNIA

TULAMNIU MOUNDS, KERN COUNTY

This site consisted of two large shell mounds along the base of the hills bordering the west side of Buena Vista Lake, near Taft. Mound no. 1 is about 1,000 feet long, 200 feet wide, and about 8 feet high at the center. This mound marks the historic Yokuts village site of Tulamniu first visited by the Spaniards in 1772. In addition to the two mounds, several burial places located on adjoining hilltops disclosed more than 400 burials and a few mortuary objects.

The large mound was trenched extensively so as to permit a thorough study of its internal structure. It proved to consist of layers of shell, ash, refuse, charcoal, sand, gravel, and loam, indicating that it had been used as a habitation site and midden for a long period. A number of circular house floors were found at different levels with peripheral post holes, cache pits, and fireplaces well shown (pl. 9, fig. 1). The burials were mostly of infants apparently thrown without ceremony into refuse pits. A single prepared burial pit contained the bones of a child accompanied by two well-made steatite vessels (pl. 9, fig. 2). A large area was excavated by layers completely through the center of the mound and carefully screened for small objects, yielding more than 3,000 specimens consisting of stone tools, flaked flint points, bone awls and needles, shell beads and ornaments, and curious balls of clay with tule rush impressions.

A homogeneous culture is indicated throughout the mound, except that European trade objects were found on the surface.

Mound no. 2 was located about three-quarters of a mile south of mound 1 on a long sand spit. About 100 burials were found scattered at various depths throughout the mound, many of them in prepared cysts or in pits evidently intended originally for cooking purposes (pl. 10, fig. 1), but few of the burials were accompanied by mortuary objects. All of the bodies were flexed except three in the deepest part of the mound, more than 10 feet down, which were fully extended.

Mound no. 2 yielded about 1,000 artifacts, which were generally similar as to class and appearance with those from mound no. 1. The only definite stratigraphy noted was with regard to steatite, which was confined to the top layers. Although the chronological relationship between the two mounds cannot as yet be fully determined, the general appearances indicate a greater age for mound no. 2. The hilltop burial sites accompanying each of the two mounds exhibit this same cultural affinity.

The bodies interred on the burial hills were flexed and wrapped in soft woven fiber cloth, and in some instances were also encased in tule mats. The remains of posts beside the skeletons evidently indicate the custom of hanging offerings or belongings of the dead person near the grave. These cemeteries contained the bodies of both adults and children, sometimes several in a grave. Later burials frequently cut through and disturbed the earlier ones. Several skeletons showed indications of violent death, as arrow points were found deeply imbedded in their bones. They had evidently been shot at close range and from several sides at once. This may have some connection with the custom known to exist among certain California tribes of killing unsuccessful medicine men.

Summary.—A brief summary of the cultural material follows:

Total Tulamni specimens, approximately 4,500.

Ground stone: Bowls, mortars, pestles, mullers, grinding slabs, hammers, balls, plummets.

Steatite: Bowls and platters, reels or spools, arrow straighteners, sinkers, grooved slabs, disks, beads, small miscellaneous forms.

Chipped stone: Arrow points, spear or dart points, knives, drills, scrapers, large blades; materials, flint, obsidian, schist.

Bone: Awls, bodkins, tubes, whistles, beads, scrapers, antler tips, straight fishhooks, one decorated bone gorget from cemetery.

Shell: Beads, pendants, and other ornaments of abalone, olivella, limpet, pismo clam; they range from large disks and tubes to tiny rings sometimes used as inlays in asphalt.

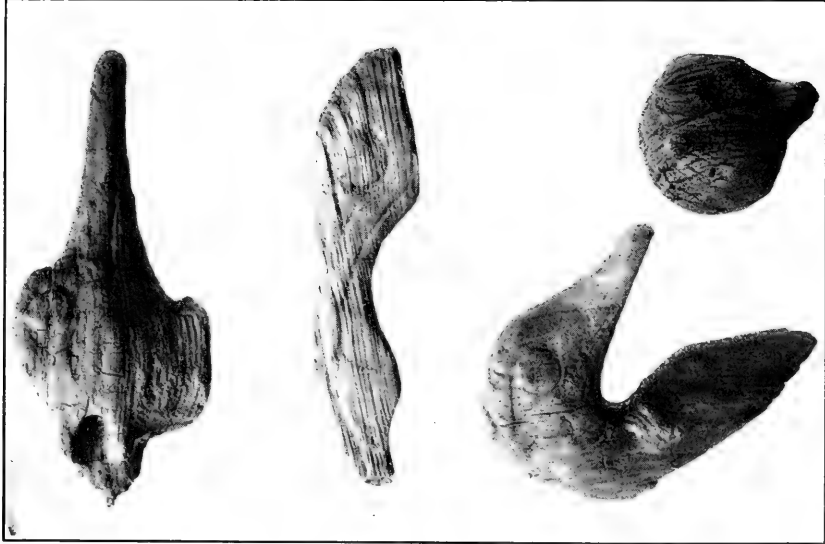
Textiles: Indications of basketry, bags, and mats of tule and other fibers, probably milkweed or wild hemp.

Minerals: Red, white, yellow paints. Clay objects in form of disks and balls with reed impressions. No pottery.

European objects: Glass and porcelain beads, bits of iron.

The culture in general is similar to that of the historic San Joaquin Valley tribes, showing a few outside contacts from the east, south and west. The general results of the work give us a good example of a simple hunting and fishing people who developed a distinctive culture in a marshy lake environment based principally upon varied uses of tule and other rushes for house material, rafts, textile fibers, burial shrouds, and even for fuel. A plentiful supply of shellfish, fish, fowl, and game made the food quest a relatively simple one. Evidently the camp sites were moved in accordance with the rise and fall of the lake level. Several wave-cut terraces high up on the mounds indicate more than one period of high water when the occupants of the site were probably forced to move.

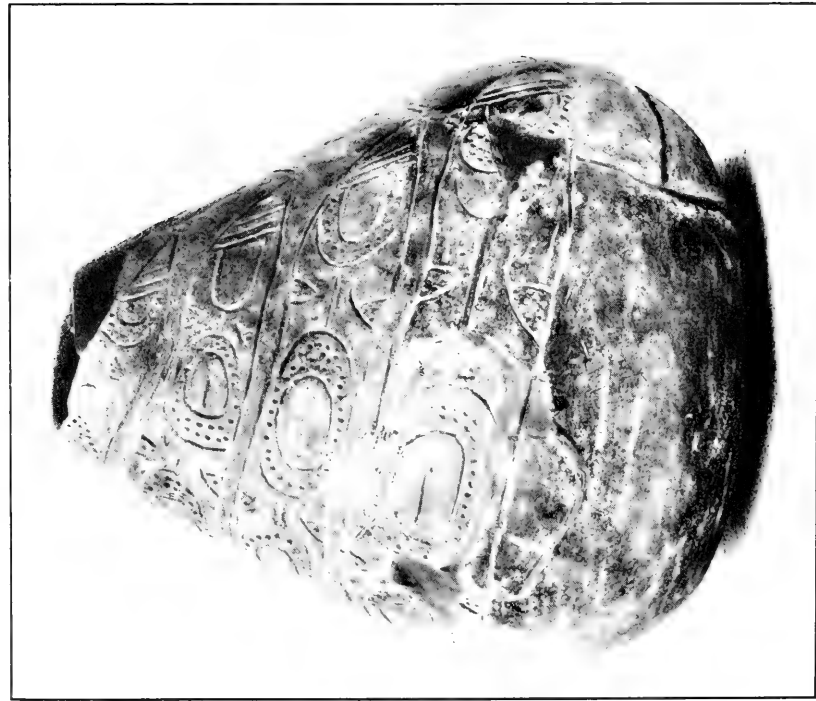
It is probable that the site was occupied for several centuries and that the population diminished rapidly after contact with the whites. The mound shows marked cultural connections with the shell mounds of the San Francisco Bay region, and it is quite possible that the builders of Tulamniu migrated from that region. No evidence has yet been found in the San Joaquin Valley of any earlier people. Trade contacts with the Shoshoneans is seen in the use of obsidian, and with the coastal Chumash in marine shells. The steatite industry in the valley was evidently late; although the material was obtained locally, the use of steatite was probably learned from the coastal people. Basketry making and weaving of mats were well developed. Asphalt was used to make water-tight baskets. These sites, which bridge the period between the historic and the prehistoric, give us a picture of a long-continued simple and remarkably static culture.



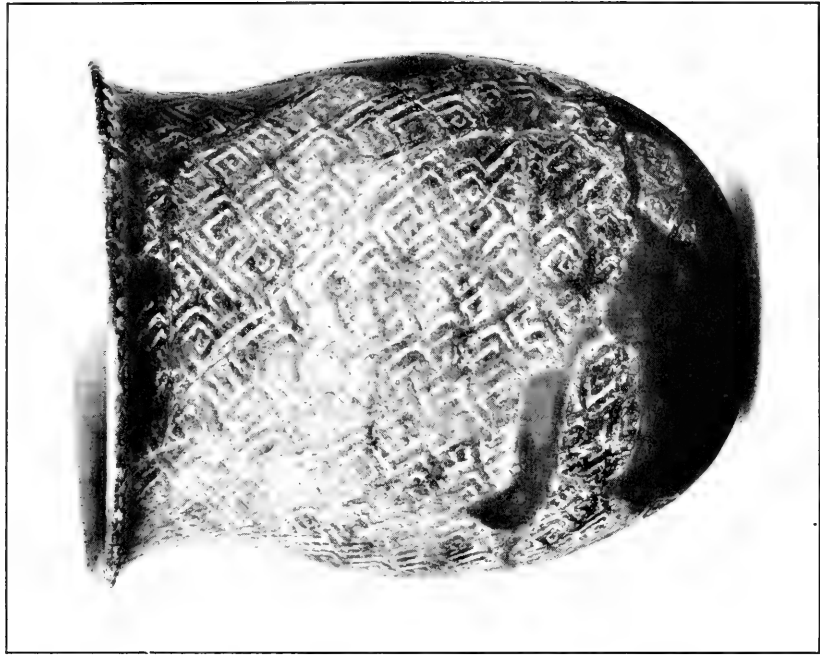
1. CARVED WOODEN BIRD HEADS FROM MUCK STRATUM, BELLE GLADE MOUND.



2. CARVED WOODEN PLAQUE FROM MUCK STRATUM, BELLE GLADE MOUND.



1. PEAR-SHAPED VESSEL WITH INCISED DECORATION FROM LITTLE MANATEE RIVER, MOUND 3.



2. JAR WITH STAMP DECORATION FROM LITTLE MANATEE RIVER, MOUND 3.



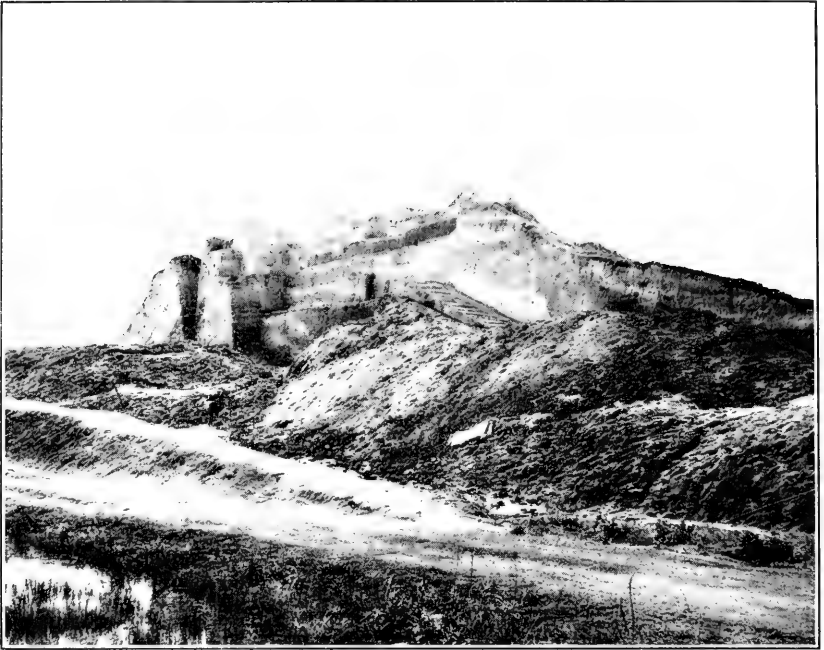
1. BASE OF MORTUARY TEMPLE, LITTLE MANATEE RIVER, MOUND 2.



2. "KILLED" VESSELS FROM ENGLEWOOD MOUND.



3. SAND MOUND ON CANAVERAL PENINSULA.

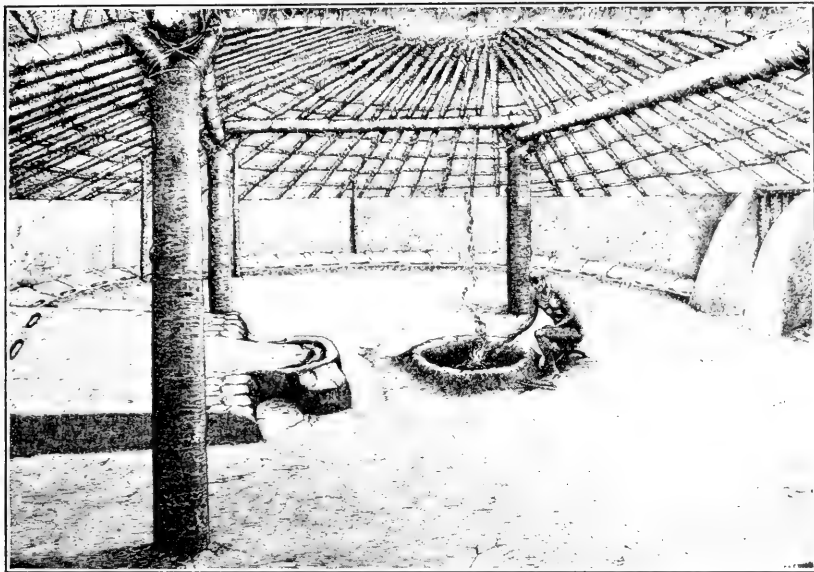


1. CROSS-SECTION OF MOUND C SHOWING SUPERIMPOSED TEMPLE FOUNDATIONS, MACON GROUP.

Note aboriginal stairway approach in right-hand corner.

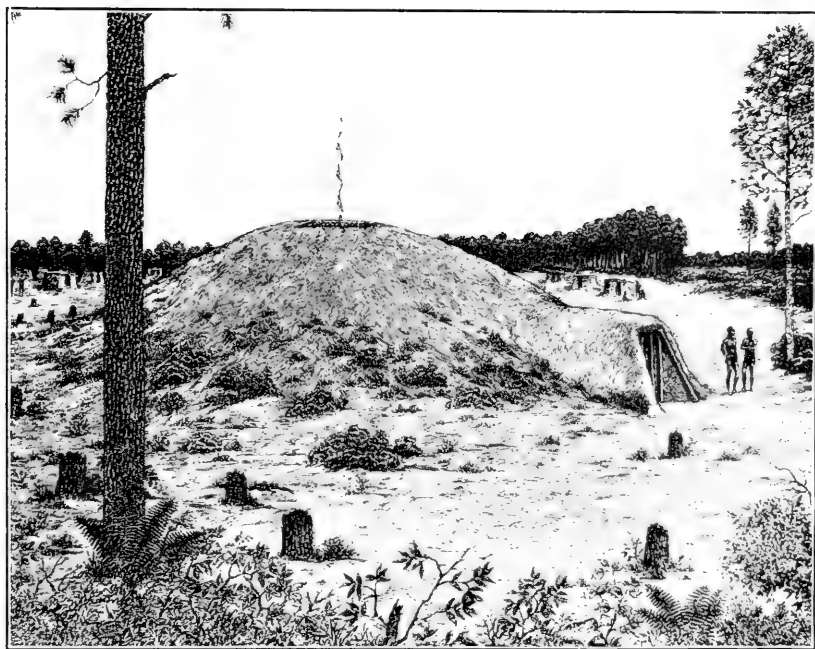


2. CROSS-SECTION OF MOUND D SHOWING HORIZONTAL CORN ROWS RUNNING UNDER MOUND. MACON GROUP.



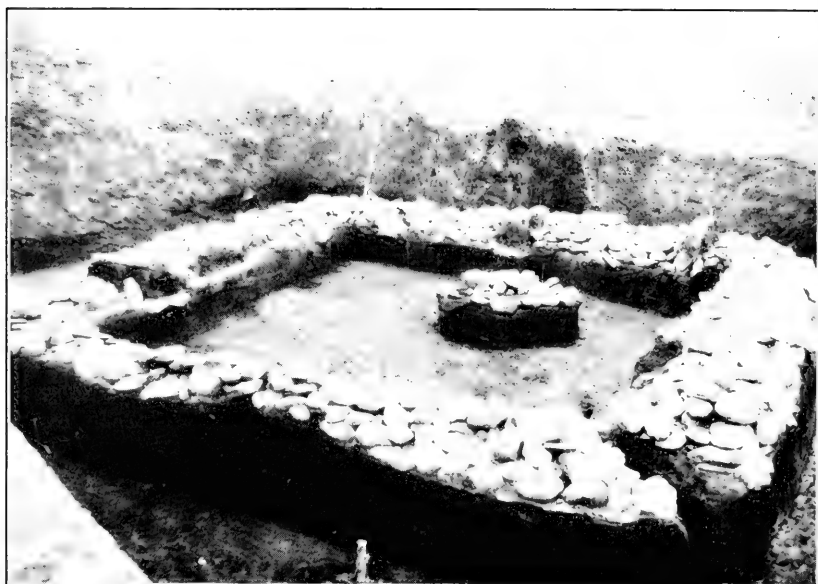
1. INTERIOR RECONSTRUCTION OF MACON COUNCIL HOUSE.

From drawing by F. C. Etheridge.



2. HYPOTHETICAL RECONSTRUCTION OF MACON COUNCIL HOUSE.

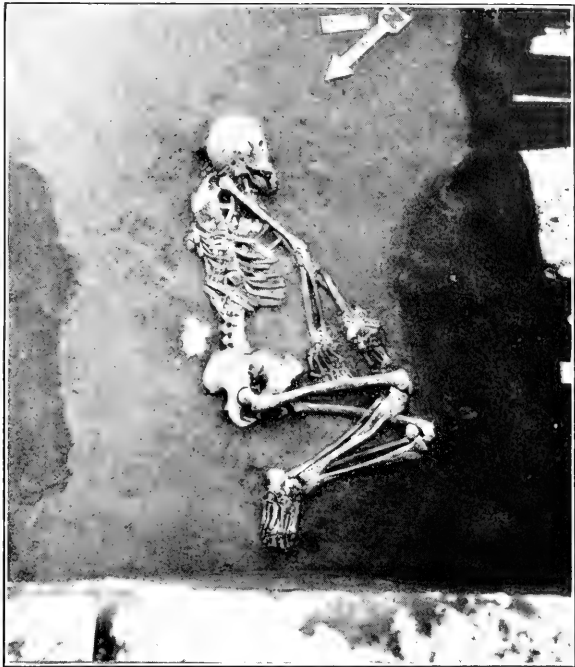
From drawing by F. C. Etheridge.



1. STONES SERVING AS FOUNDATION FOR WALLS IN PEACHTREE MOUND. NORTH CAROLINA.



2. STONES REMOVED SHOWING PREPARED FLOOR. NOTE SMALL COMPARTMENT WALLS ABOVE FLOOR. PEACHTREE MOUND.



1. BURIAL BENEATH BASE OF PEACHTREE MOUND WITH SHELL BEADS AND TWO WOODEN EAR ORNAMENTS COVERED WITH COPPER.



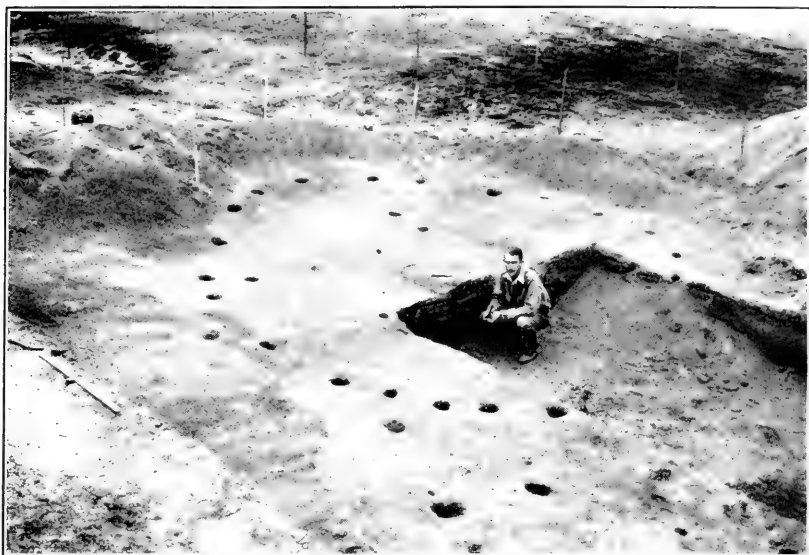
2. INTRUSIVE STONE-LINED GRAVE IN PEACHTREE MOUND.



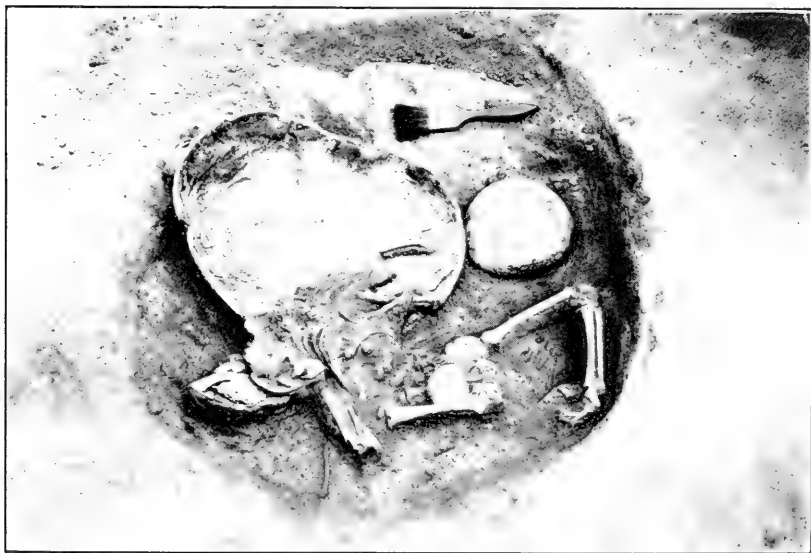
1. EXPLORATORY TRENCHES BETWEEN ABORIGINAL MOUNDS, SHILOH NATIONAL PARK, TENNESSEE.



2. SECTION OF BURIAL MOUND, SHILOH NATIONAL PARK.



1. FLOOR PLAN OF YOKUTS' HOUSE SHOWING POSTHOLES AND FIREPLACE.
TULAMNIU, MOUND 1, CALIFORNIA.

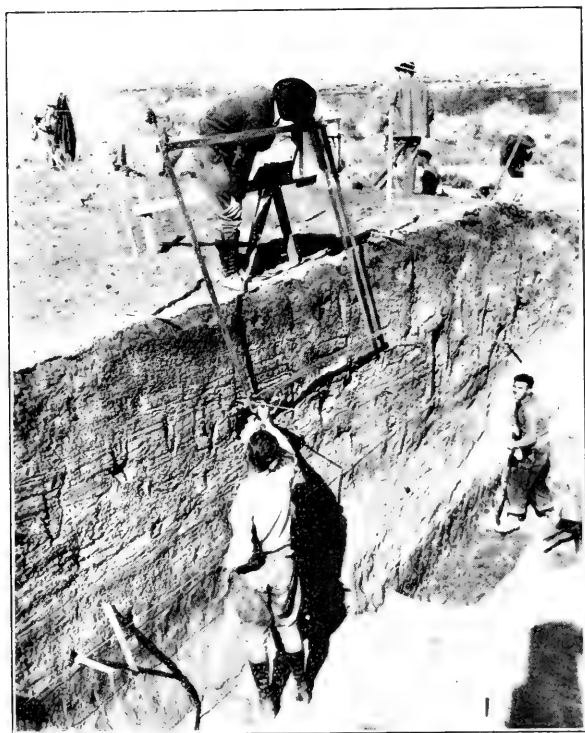


2. BURIAL OF CHILD WITH TWO STEATITE BOWLS. TULAMNIU, MOUND 1.



1. HOUSE FLOORS, FIREPLACES, AND COOKING PITS EXPOSED AT MOUND 2, TULAMNIU.

Many of the cooking pits had later been used for burial purposes.



2. NEW TYPE "STRATAGRAPH" USED IN MAKING RAPID AND ACCURATE DIAGRAMS OF DEEP STRATA AT TULAMNIU.

INDIAN CULTURES OF NORTHEASTERN SOUTH AMERICA

By HERBERT W. KRIEGER

United States National Museum

[With 12 plates]

NATIVE TRIBES AND LANGUAGES

Indian tribes occupying northeastern South America come roughly within a grouping consisting of four large linguistic stocks—the Tupí, the Tapuya, the Arawak, the Carib—and of several smaller ones. The checkered geographic arrangement of two of these, the Arawak and Carib in northern South America, east of the Andes, is remarkable. Various theories have been developed to account for this. The most widely accepted and most plausible theory, although not necessarily the most correct one, is that as the Caribs were war-like and the Arawaks peaceful, they were continually engaged in warfare and migrations, with the Arawaks in the lead closely followed by marauding bands of Caribs. Perhaps the only authority for this is observations made by Spanish explorers on the Lesser Antilles at the time of their discovery, when the Caribs were actively on the trail of the Arawaks, dispossessing them of their women and driving them out of their island homes. At this time, so it is conjectured, the Caribs had supplanted the Arawaks in the Lesser Antilles, an island archipelago which extends all the way from the delta of the great Orinoco River, and the outlying island of Trinidad in the Gulf of Paria on the Venezuelan coast, to Vieques just east of Puerto Rico.

Undoubtedly several explanatory factors in addition to the harassment of war should be taken into consideration in accounting for the widely scattered Arawak and Carib tribes in the South American mainland north of the Amazon. Many of the early documents and narratives treating with tribal distribution in tropical South America refer to tribes no longer occupying the areas mentioned in those accounts. In other words, the displacement forces are still at work.

Most of the tribes of the tropical rain forests, savannas, and coastal plains practice a tropical agriculture based on cassava, but are at the same time seminomadic hunters and fishermen. Milpa agriculture, or the planting of root crops in a forest clearing which is abandoned after a few seasons, would alone suffice to account for extensive tribal wanderings in the course of a century.

The distribution of Indian tribal stocks in northeastern South America is not well known. The field is a large one, larger than the entire area of the United States including Alaska, and the native population is widely disseminated. The accounts of early explorers, often the only source material available, remain uncorrected as to details but are authoritative within a broad outline. The researches of noted scholars in the area, such as Koch-Gruenberg, Lehmann-Nitsche, Chamberlain, Nordenskiöld, Von den Steinen, Farabee, Fewkes, Stirling, Karsten, Krause, Rivet, Von Rosen, Schmidt, Steere, Jahn, Joyce, DeBooy, Im Thurn, Roth, Brett, Lange, Linné, Netto, Hartt, Pinot, Ernst, Church, Von Ihering, Ehrenreich, Göldi, Petruccio, and Brinton, have determined within broad outlines the linguistic, cultural, and geographical boundaries of the more comprehensive groups.

ETHNIC MAPS

An excellent map of the "Country and Environs of the Guiana Indians", appearing in the 38th Annual Report of the Bureau of American Ethnology, was compiled by Dr. W. E. Roth from the maps of Crevaux, Condreau, Schomburgk, Koch-Gruenberg, the Venezuelan War Department, and the Mission Bresilienne d'Expansion Economique. There is also a tribal map covering all of South America in "The American Indian", by Clark Wissler. This map is based on original sources and brings out the relation of the tribes to the larger linguistic groups perhaps more clearly than in the original sources. Chamberlain's "Linguistic Stocks of South American Indians", published in the *American Anthropologist* (n. s., vol. 15, no. 2, April-June 1913), has a distribution map extensively used as a source reference. The excellent tribal distribution map appearing in Buschan's "Voelkerkunde", Stuttgart, 1922, was carefully compiled by Dr. Krickeberg, and is based on the work of Chamberlain, Koch-Gruenberg, Lehmann, Rivet, Outes, and Joyce. The map accompanying this paper is an adaptation of the Roth and Buschan maps. In it an attempt is made to outline tribal as well as linguistic areas.

The topography of northeastern South America is simple, consisting of highlands in the southern and eastern portions of Brazil and surrounding low plains. To the northwest the low-lying country drained by the Orinoco and by the Amazon and its tributaries is

covered with a dense forest; the lowlying plains on the southeast are periodically inundated when the Uruguay and Parana Rivers

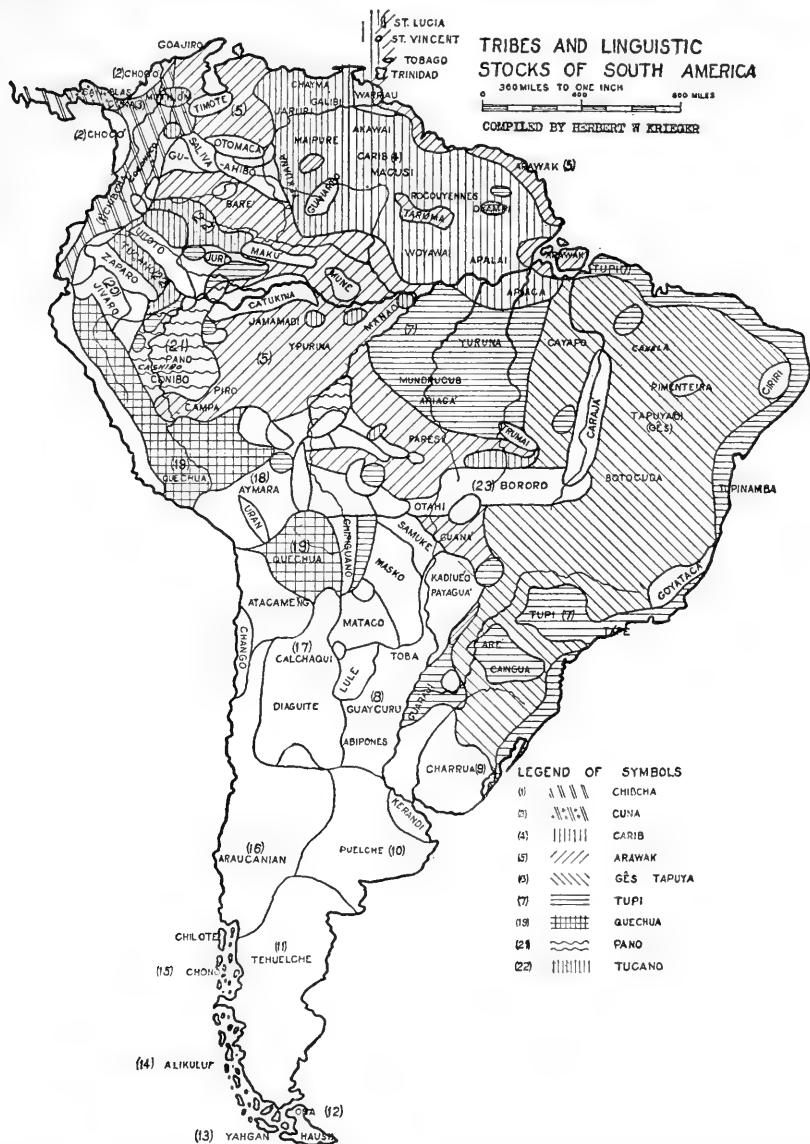


FIGURE 1.—Ethnic map of South America illustrating the diffusion of native linguistic stocks. A small number of representative tribes belonging respectively to the Carib, Arawak, Tupi, Tapuya and other stocks are named and located. The smaller independent linguistic stocks are named and numbered on a background of white.

rise in flood. The most easterly point of Brazil, Cape Branco, forms the apex of a triangle whose base runs in a diagonal direction along the eastern slopes of the Andes and across Paraguay, terminating in

Rio Grande do Sul, southern Brazil. This area includes the three Guianas, Venezuela, all of Brazil, parts of Colombia, Bolivia, and Paraguay. Although there are the several large streams, the Orinoco, the Paraguay, and the Parana, it is usually referred to as Amazonia. Owing to their nearness to the mainland and to the strong northerly trend of the prevailing ocean currents, the native population of the islands of the West Indian archipelago must be included with tribes of the rain-forest areas of tropical South America.

The provinces of northern Argentina and the grassy plains of the vast Gran Chaco which characterize the territory west of the Parana, afforded little incentive toward the diffusion of the higher cultured upland Andean peoples. In Uruguay a spur of the western uplands becomes a rolling plain similar to the Argentinean pampas. It was occupied by a roving, nomad, hunting population. The central upland of Brazil with its grassy savannas is infertile and subject to periods of drought.

A physical population chart classifying the native peoples of east and central South America according to anthropological measurements has not been formulated, owing to lack of adequate data. It has been supposed that many of the isolated tribes with a general culture complex distinct from that of the larger linguistic stocks might be remnants of an earlier migration. This has never been definitely determined, owing to lack of comparative data. In fact, unpublished data on the language of the Botocudo of eastern Brazil, previously thought to be a population remnant, point to remote affiliation with a large linguistic stock. The work of Ameghino and others has led to the presupposition of Quaternary men in eastern Brazil and northern Argentina. The inhabitants of this area conform, however, according to Hrdlička, to the general description of Indian physical stocks resembling in a broad way the tribes of other South American areas and of middle America more than the peoples of Oceania or Africa. They have straight black hair, brown skin of various shades, are of medium height, and have a diversity of appearances stamped with more or less tropical or apathetic dispositions.

DENSITY OF NATIVE POPULATION

The complete annihilation of the Arawak and Carib occupants of Cuba, Haiti, Santo Domingo, Puerto Rico, the Lesser Antilles, and the Bahamas during the days of the great Spanish gold rush beginning with the settlement of Santo Domingo in 1499 is illustrated by the few remaining "black" Carib settlements, more negroid than Indian, still existing in St. Vincent and Dominica.

In the year 1793 a large number (approximately 5,000) of "black" Caribs were taken by the English from St. Vincent in the Lesser Antilles to Ruatan, Honduras. Their descendants, strongly mixed with Negro strains, today occupy settlements along the Honduran coast from Stann Creek to Carib Town, Nicaragua. Thoroughly negroid in appearance their language is Carib and their culture remains South American.

The treatment suffered by Amazonian Indians of Brazil in connection with the rubber industry has decimated them. Concentration of Indians in missions like those of early California days is still practiced on the Putumayo of Colombia; also in Argentina, as in California, we speak of the Mission Indians. This encomienda system led to the extinction of entire tribes in Paraguay and Bolivia, where the present war in the Gran Chaco may lead to the extermination of still other Indian population groups.

Spinden estimates the present native Indian population of several of the South American countries as follows:

Colombia and Venezuela-----	3, 000, 000
Ecuador, Peru, and Bolivia-----	6, 000, 000
Brazil, Paraguay, Uruguay, and Guianas-----	4, 000, 000
Argentina and Chile-----	200, 000
	<hr/> 13, 200, 000

SCIENTIFIC EXPEDITIONS AND ETHNOLOGICAL COLLECTIONS

In 1851 Lts. William Lewis Herndon and Lardner Gibbon, United States Navy, were sent by the Navy Department to secure information as to the feasibility of introducing steam navigation on the waters of the Amazon with a view to promoting commerce. It was decided to divide the party, Herndon taking the headwaters and main trunk of the Amazon and Gibbon the Bolivian tributaries and following down the Madeira to the Amazon. The account of their journeys was published in 1853 as a public document of the Thirty-second Congress, second edition, under the title "Exploration of the Valley of the Amazon Made Under the Direction of the Navy Department by William Lewis Herndon and Lardner Gibbon, Lieutenants of the United States Navy." The ethnological specimens collected are now in the United States National Museum but are not specifically identified as to locality.

Herndon describes interestingly the manufacture of rubber shoes. He also describes in detail the making of figures of animals of rubber by repeated dippings of a core, the decorative pattern being put on with a heated wire. These collections made nearly a century ago, before the value of objects of material culture was much appre-

ciated in science, have no data as to the tribes and exact localities. It was thought enough to say the Rio Purus, the Rio Negro, and many specimens have the localization "Amazon River"!

In recent years several explorations of more or less extensive planning and facilities for ethnological research have been undertaken in the area of the middle and upper Amazon and Orinoco River valleys. One of the more notable of these was an expedition sent out by the United States Department of Commerce to investigate the crude rubber industry in its original home. Members of this expedition traveled more than 20,000 miles on 37 distinct rivers of the Amazon system. This expedition also ascended the Rio Branco as far as the Campos country of the borderland of the Guianas. Another, the Alexander Hamilton Rice Scientific Expedition, recently covered the area drained by the Parima River and the headwaters of the Amazon in northwestern Brazil. This expedition was accompanied by the anthropologist, Dr. Koch-Gruenberg, well known for his earlier explorations and careful observations on the ethnology of northwest Brazil and Venezuela. It had as its object the surveying and mapping of the Rio Branco and its western affluent, the Rio Uraricoera, in order to ascertain whether any passage existed between the headwaters of this river and those of the Orinoco. The ethnological activities of the Latin-American Expedition to eastern Peru and Ecuador were in charge of M. W. Stirling, Chief of the Bureau of American Ethnology, whose activities resulted in a collection of type specimens of the material culture of the Chama, Jivaro, Auaruna, and other tribes. Still another recent expedition was that conducted by Herbert Spencer Dickey in much the same area as the one just mentioned. But little has thus far been accomplished by way of exploring the practically unknown area reaching from the interior of the Guianas to the headwaters of the rivers draining into the Amazon.

Much of the ethnological field work among the tribes of northeastern South America has been done by European scholars, notably Koch-Gruenberg, Nordenskiöld, and Roth. The work of Walter Edmund Roth deals mostly with the Indians of British Guiana, of Arawak and Carib linguistic stocks, such as the Arecuna, Makusi, the Wapishana, and the Atorai. The Carib tribes studied by W. C. Farabee, of the University of Pennsylvania, in more or less detail as to environment and material culture, are the Macusis, Waiwais, Waiwes, Parukutus, Kutcifinas, Chikenas, Katawians, Diaus, Tonayenas, Wakeras, Kumayenas, Urukucenas, Apalaiis, Macara, and tribal remnants of the Zapara, Azumaras, and Porokotos.

A large number of collections of ethnological specimens have been accumulated by the United States National Museum from the tribes

of northeastern Brazil, of Surinam and the Guianas, of Venezuela, Colombia, eastern Peru, Bolivia, northern Argentina, and of Paraguay. The extensive ethnological collection of Dr. Roth, on which his work is in part based, was acquired by the Bureau of American Ethnology and transferred in 1916 to the National Museum. The most comprehensive ethnological collections in the United States National Museum from Indian tribes of tropical South America are representative of the arts, crafts, and ceremonial practices of the Guiana Carib and Arawak. There are in the National Museum also ethnological specimens from the Arakuna, the Makusi, Patamona, Taruna, Wapisiana, Warrau, and the Akawoise of Dutch and British Guiana.

Brazil is represented by ethnological specimens from the Jama-madi, Roucouyenne, Tucuna, Bororo, Yagua, Guapore, and Hypurina tribes. The ethnology of Paraguay includes objects from the Chuna, Tobo, Guarani, Guaycuru, and Chamacoco. Represented in the ethnological collections from northern Argentina are the Mission Indians, the Chorote, Chiriguano, Mataco, Chulupi (Thulupi), Tiki, Lengua, Landi, Jujuy, and Calchaqui; from Peru the Napo, Chama, Canelo, Cambria, Orejon, Anishira, Cashivo, Chapo, Conibo, Omagua, Ucayali, Lorenzo, Titicaca, Quichua, Puno, and Piro tribes; from Ecuador the Jivaro, Cayapas, Chinganase, Aguaruna, Chubijas, and Zaparo tribes; from Colombia the Cuna, Jorico, Anshire, Popoyan, Bush Negro, and Choco tribes; from Bolivia the Amasari, Chuno, Chiriguano, and Aymara tribes; and from Venezuela the Motelone and Goajiro tribes. These tribes are typical of the ethnology of the geographical region they occupy, and the ethnological collections in the United States National Museum from each of them are included under one or more accessions. Several accessions remain unclassified as to tribal origin though identified geographically.

TRIBES OF THE SOUTH AMERICAN RAIN FORESTS, SAVANNAS, AND COASTAL PLAINS

If we begin our classification of northeastern South American Indians with the tribes just north of the La Plata River, namely those occupying Paraguay, Uruguay, and the more temperate regions of Brazil, principally the province of Rio Grande do Sul, we have the early home of the great Tupí linguistic stock. Tupí tribes were encountered by the early European voyagers and explorers along the east coast of Brazil and the shores of the Amazon as far upstream as the mouth of the Rio Negro. Most of these tribes have been displaced from their original home through the forward drive of Spanish and Portuguese settlements. However, many pure Tupí

tribes in the interior have retained their independence. Foremost among these is the Guarani, whose language is still commonly spoken in Paraguay, and the Kaingua and Aré of southern Brazil. Other Tupí tribes living on the Upper Marañon are the Kokama and the Umáua (Omagua) who have possibly found their way to the Marañon from the Gran Chaco by way of the Ucayali River. This tribe understands river navigation. The principal food of its people is roasted manioc meal. They also fish in season, drying a certain amount and grinding it up as provisions for future use. They live in large communal houses covered with palm-leaf thatch and construct palisades around their villages. They weave hammocks in which they sleep and under which they maintain a continuous smudge fire. They wage war on neighboring tribes and are cannibals to the extent of eating their enemies. Their own dead they conserve in large burial urns (igaçaba). Their speech is the universal language of the early missions and early traders, generally used by the whites and Indians in widely separated parts of Brazil. In its modern form, the "lingua geral", the language of the Tupí is the "lingua franca" of tropical South America. Today it is rapidly giving way to the use of Portuguese.

The Tupí tribes of the coast and along the river courses may be contrasted with tribes of the interior who live to a large extent from the chase. These tribes of the Brazilian interior are grouped under the generic term "Tapuya", generally known as the Gês tribes, so named because many of the tribes of this linguistic stock have names ending with the syllable -gês (g equivalent to the French j). These tribes do not have boats or hammocks; consequently they are called barbarians by the Tupí. Many of the Gês tribes are characterized by the wearing in their lower lip of large brown disk labrets. Northern Tapuya live in northern Brazil in the province of Pernambuco and Rio Grande do Norte.

The Gês were the earliest known occupants of the Brazilian uplands. Their many extensive migrations have left tribal remnants at widely scattered points and no one large area is at present predominantly inhabited by Gês tribes. Today in the main, while the Carib and Arawak occupy the Amazon and Orinoco River plains, the Tupí-Guarani and Gês inhabit the remainder of the huge tropical forest and savanna area insofar as it is at all occupied.

Westward and northward of the Gês tribes there are two large linguistic stocks only recently distinguished as to their original habitat. These are the Caribs and the Maipure (Nu-Arawak) tribes. The original home of the Carib was probably in the interior in the vicinity of the Upper Xingu, the most primitive type of Caribs encountered by Von den Steinen. From here the Caribs emigrated northward into the Brazilian province of Amazonas, gradually oc-

cupying the Amazon and Orinoco River valleys. Numerous tribes belonging to the Carib today occupy Guiana and northeastern Venezuela. From the mainland they have within historic times even penetrated the islands of the Lesser Antilles as far as Puerto Rico and eastern Hispaniola, everywhere battling and defeating the Arawak inhabitants. Outposts of the Caribs in Colombia on the Rio Cesar and Venezuela are the fierce Motilones. The Karijona and the Uitoto live on the Yapura, one of the northern tributaries of the Upper Amazon.

The Carib is the least influenced by Negro or white traits, retaining in some villages the *peaiman*, or medicine man. The fringed breechcloth and the ligaturelike leg and arm bands of woven cotton are retained. Bows and arrows are still used, baskets are woven, and ceremonial dances are held in which feather crown headdresses, teeth necklaces, and cotton head ornaments are worn, and in British Guiana the ceremonial wooden club is retained, as is also the blowgun and poisoned darts.

The Maipure (Nu-Arawak) linguistic stock appears to consist of the two branches of the "Nu" tribes, so named from the prefix "Nu" which they bear in common, and of the Arawak tribes. To the Arawaks proper of the Guianas belong the Goajiro, who occupy the peninsula of the similar name in extreme northern Colombia. At the time of the discovery of America the Nu-Arawak occupied the coast land of Colombia and adjoining countries as far eastward as the mouth of the Amazon; also the great West Indian islands of Puerto Rico, Hispaniola, Cuba, and Jamaica. In the Goajiro Peninsula of extreme northern Colombia, the Goajiro have maintained their independence to the present day. On the Orinoco, the Maipure, and in Guiana, the true Arawaks still constitute a striking and important element of the population sharply contrasted with the neighboring Carib tribes.

In the vicinity of the mouth of the Amazon, the Nu-Arawak tribes are practically exterminated, but their speech has been preserved and the burial offerings recently uncovered in the Island of Marajó testify to the richness of their ancient culture. From the Orinoco and the Guianas the Nu-Arawak tribes extend in a broad band toward the southwest to the mountain valleys in which the tributaries of the Upper Amazon take their origin. They have also extended their territory farther toward the east to the source of the Xingu and to the southeast to northern Paraguay. The Carib and the Nu-Arawak make a flat bread from manioc (Cassava) meal and understand the weaving of hammocks. The Caribs weave their hammocks of cotton, but the Nu-Arawaks use woven bast fiber. The Carib tribes are among those noted for their efficient poison darts and their beloved hunting weapon, the blowgun, which, however, is also

in use among other forest tribes. The Arawak are distinguished by the excellence of their pottery, notably of that from the prehistoric period of the Marajó and West Indian areas.

West of the Caribs and of the Nu-Arawaks are two smaller linguistic groups. One of these, the Pano, consists of two tribes living on the Madeira and Madre de Diós and on the Middle and Upper Ucayale, separated from one another by some of the Nu tribes, namely the Ipurina, Piro, and Campa. The other, the Tukano and related tribes live north of the Amazon on the Yapura and Rio Negro. Scattered throughout the area are smaller linguistic stocks and tribes as yet not classified as belonging to any of the larger linguistic stocks, but whose culture approaches one or the other of their more powerful neighbors. Examples of these unattached tribes are the Puri or Coroados in Rio de Janeiro, the Bororo in the Matto Grosso and the Karajá on the Araguaya, the Waupe on the Rio Negro, the Tekuna, Yahua, and some 30 tribes of the Chiváro (Jivaro) on the upper Amazon tributaries. Another unattached tribe, the Warrau, or Guarano, once lived in pile-dwellings in the swamps surrounding the mouth of the Orinoco.

TRIBES OF THE GRAN CHACO

A large geographical area occupied by a number of different tribes unrelated to the western Andean uplands but more or less closely bound culturally if not geographically to the Amazonian section is that of the Gran Chaco. This is an extensive rolling woodland country west of the Parana River entirely to the north of the Argentinean Pampas. Its eastern boundary is the Paraguay River and its western edge is skirted by the foothills of the Bolivian Andes. On the north it merges into the forested area of the Amazonian tributaries. The Gran Chaco is an inhospitable rolling terrain subjected to drought and floods, and endowed with an infertile soil. Some of the tribes, the Lule, Vilela, and Matakó, have not yet made the acquaintance of the horse, whereas others, Abipones, the Toba, Makobi, Guaicuru, are known as "equestrian tribes." These latter are more or less linguistically related. In the north of the Gran Chaco the agricultural Tupi tribes of the Chiriguano have made settlements. In the mountain valleys of the Salta, Jujui, and Tucuman in the Argentine west of the Chaco live the Calchaqui (Diaguita or Kaltschaki), the warlike agricultural tribes whose culture corresponds in many respects to that of our Pueblo Indians of the Southwest. They have been Christianized, and their racial purity has been submerged in a Spanish-Indian hybrid folk. They have the Andean practice of building houses of stones set in mortar. As in the entire western portion of the

Chaco and of Amazonia, we have among them strong Peruvian influence. Characteristic of this group are the well-known Payaguá, formerly much feared because of their piracies along the Paraguay River. During the years 1740 to 1790 they were conquered and forced to settle in the Province of Asunción.

There extends from the vicinity of the Argentinean and Bolivian Chaco up to the Brazilian Matto Grosso the group known as the "Guaicuru." These were equestrian tribes equipped with short bows and reed arrows. Their habits of life resemble those of the more southerly Chaco and Pampas Tribes. They have, because of their warlike disposition, provided constant danger for the outlying settlements and for travelers. However, one of these tribes, the Cadiueó in the Matto Grosso, has shown a friendly spirit in its intercourse with the culture settlements.

Some of the tribes of the Guaicuru are the Abipone, Toba, Mbocobi, Mbaya, and Cadiueó. The Abipone were exterminated by the Toba in historical times and are well known only from early literature. The Guaicuru were excellent hunters and fishermen, the Cadiueó being slightly acquainted with agriculture and weaving. The Cadiueó were also expert potters. Their weapons were clubs, lances, and bows and arrows; knives, before the introduction of iron, were made from the teeth of the pirana fish or of shell or stone. Scalping and head hunting were engaged in with the aid of such weapons. A loin covering, a robe of skin, and little else constituted their wearing apparel. Women were addicted to profuse tattooing about the face, and the men painted their bodies with the juice of the genipa. Clans and clan chieftains, communal houses, and medicine men all are reminiscent, along with scalping, of the Plainsmen of North America.

Other stocks of the Gran Chaco are the Lule, Mataco, Payagua, and Charrua. The Payagua are not equestrian and live on the banks of the Paraguay River. The Charrua of the Uruguay River area, like their Patagonian relatives, are oarsmen and use the bola. Earlier Chaco tribes are the Lengua, Tööthli, and Suhin.

The Chamacoco, Lengua, Tumraha, and Macikui tribes of the Gran Chaco occupy small settlements made up of *toldos*, houses roofed with grass or palm-leaf thatch. Each communal house includes the members of a separate clan, divided into family groups.

The Gran Chaco is subject to drought and floods. Because of unfavorable environment, the agricultural habits of the natives are elementary and limited to what might be called food gathering. Wild honey, wild beans, palm shoots, and vegetables are collected. Game and fish are eaten rather than the flesh of domesticated animals. The pepper-pot of the tropical forest tribes is simulated.

The meat of game is cooked; fish are roasted. Tobacco is cultivated for local use, not for trade purposes.

The crafts of Gran Chaco tribes are represented by carrying-pouches of netted fiber, and by finer gourd and calabash receptacles. Women dress themselves in a blanket of woven cotton bearing decorative patterns representing trails, palm-trees, snake-skins, or realistic objects drawn from nature. This robe may be suspended from the waist or shoulder, depending on weather variations. Sandals of rawhide are worn as a protection against thorns and briars. There is also a ceremonial sandal of antbear skin. A skirt of sewn skins is worn for everyday use. Men wear sandals of rawhide and a fringed girdle of skin.

Festival attire is the order of the day throughout the Gran Chaco and Amazonia generally. Headdresses and girdles of parrot, macaw, duck, and rhea feathers, belts with pendant deer hoofs or snail shells, girdles of seeds and human hair, and pendants of antbear claws and hollow bones are affected. Necklaces of bright-colored seeds, trade glass beads, turtle bones, and animal teeth are much in evidence.

DIFFUSION OF CULTURE TRAITS

There is practically no break in the complex of mountains extending along the western front of the American continents, so that it would be possible from a geographical standpoint for Indian tribes accustomed to living in a temperate environment to continue in their migrations southward from the North American to the South American highlands. The complex of culture traits centering about the use of the loom, the possession of Isthmian gold, and pottery techniques, the raising of domesticated plants, notably maize, potatoes, and cotton, could continue uninterruptedly as the higher-cultured peoples pushed southward.

The intrusion southward into Panama of Nahua culture traits is counterbalanced by the linguistic penetration northward into Panama and Costa Rica of Colombian Chocó and Cuna stock languages. In the West Indies occurred the historic linguistic, cultural, and physical penetration of South American Arawak and Carib stocks from the Orinoco area. These immigrants were preceded by an earlier, cruder people, the Ciboneyes, whose original home in North or South America remains an unsolved puzzle, a hang-over from Solutrean days according to Harrington. It is likely that the insalubrious Isthmian belt, a sinuous mountain and jungle stretch many hundred miles in length, did not long detain immigrating tribes from the north accustomed to a more temperate upland valley climate. At any rate they built no stone palaces and temples in the Isthmian jungle. The

backwash of South American peoples northward from the Magdalena, Cauca, and Orinoco River valleys apparently did not eventuate until after a long period of Indian occupancy of the South American highlands.

The great triangle of eastern tropical woodlands which actually includes more than one-half of the South American continent may be considered as a cultural backwash from the civilized Andean groups. Many of the traits so remarkably developed in the upland actually are disseminated throughout the tropical forest area. This includes the horizontal loom and the making of pottery. The tropical forest area includes the basins of the three large rivers, the Amazon, the Orinoco, and Parana, and is almost entirely within the tropics. We would naturally expect, therefore, to find many culture traits unrepresented here because of environmental conditions that in temperate climes would be a prime requisite to existence. Thus, use of clothing is negligible, although the knowledge of the loom and of weaving is almost everywhere present. The use of woven fabrics in this huge jungle area, primarily for ornamental and decorative purposes, is scarcely at all utilitarian. Then too, many objects of daily use can here be found in their natural state and shaped with a minimum of physical exertion into objects substituting for the more finished products of higher cultures. Thus, a calabash substitutes for a pottery or earthenware cup, a rude palm-leaf thatched hut substitutes for a stone structure, the cultivation of a root crop, manioc, requiring but little care and practically no cultivation, substitutes for the care-loving maize. Fibers are everywhere plentiful for cord and tying purposes, no woven fabric cord being required. The domestication of animals is less a prime requisite because of the abundance of vegetable products. Skin clothing of the peoples of Patagonia and of the Andean uplands are replaced scarcely at all. The chipped stone weapon points of temperate South America, including the stone scrapers and knives, all revealing a chipping technique identical with that of temperate and upland North America, are entirely lacking in Amazonia and in the West Indies. This may in part be ascribed to absence of stone suitable for chipping, but is more likely due to the lack of need for such cultural development. The sharpened palm-wood lance and fish spear, the foreshafted arrow, and the use of fish poisons serve the same utilitarian purpose with the minimum expenditure of energy.

The large number of traits of Amazonia characteristic of tropical peoples elsewhere, but differing sharply from those of the Andean uplands, have led to many discussions as to the distinct origin of Amazonian Indian tribes. Migrations from some oceanic home is suggested. Another explanation pointing to the solution of the prob-

lem is the isolation of the forest tribes. While the Andean peoples occupied a very narrow strip with open valleys extending north and south along the coast, all in an arid or semiarid region, the many tribes of the tropical forest area lived in scattered settlements separated frequently by impenetrable forests and waterways. We may, therefore, look to local development of culture and to the development of many local inventions entirely distinct from those of the upland Andean peoples.

To be sure, the use of metals never penetrated the South American tropical lowlands. Not only was there no ore or deposits of free metal in this huge area, but the inhabitants had not had sufficient contact with the metal-using and producing upland tribes to become accustomed to the superior things that metal-work could produce, such as weapons, implements, ornaments, and ceremonial objects. The hardwood club, the *macana*, so widespread among the Arawak and Carib of the Orinoco Basin, was not used by the upland Andean peoples. The symmetry and beauty of this weapon was such that had an adequate supply of similar wood been available, the Andean peoples undoubtedly would have initiated its use.

The polished stone club head known as the celt, the polished mealing stone, and the general use of polished stone throughout tropical South America and the West Indies is perhaps one indication that there was a cultural contact with the Andean peoples and a cultural infection or borrowing of those things environmentally suited. There is also a stream of cultural borrowing, so to speak, within the area strongly related to southern Middle America. This is manifested for the most part in stone carving, in the use of polished stone objects generally, and also in the ornamental pottery appendages such as handle lugs of earthenware vessels in prehistoric Chiriqui and in the prehistoric Arawak of the West Indies, the Guianas, Venezuela, and the Amazon Valley.

A cultural description of the tribes of the more inaccessible parts of Amazonia would show these people as still unaffected through contacts with Europeans. Absolute nakedness is practically never encountered, although clothing is for the most part merely ornamental. The hair is usually unshorn, worn long at the back but cut in a fringe across the forehead. Headbands or headdresses of gaudy description emanating from a woven or plaited base are worn, however, mostly on ceremonial occasions. Necklaces of highly colored beetle elytra, of seeds, of monkeys' and jaguars' teeth, and beads of various descriptions are common. Nose rings are worn, that is, the septum of the nose is pierced and a nose ring or pin may be inserted. Ear labrets are worn. Either the lobe or the outer fold of the ear is perforated for the insertion of disks, feathers, or other ornaments.

Lower lip labrets, consisting either of a wooden disk or one of metal or stone, are worn. Large discoidal and ear lobe labrets are worn at the same time by some of the more primitive tribes, such as the Boto-cudo. This practice of distending the ear lobe is carried to exaggeration by the tribes of the Upper Tocantins and Araguaya Rivers.

Tattooing is fairly generally practiced, the faces of some of the women of some of the tribes being elaborately patterned. Body painting, a common practice among many tropical peoples who have dispensed with clothing, is limited to the northern part of this area. Communal houses are probably more common than is generally known throughout the area. Houses are rectangular or circular in outline, are built of posts and have a ridge roof covered with palm leaves or grass thatch. Wattling is omitted entirely, the ends and sides being left open. Palisaded villages are common. An easily understandable architectural practice is the widespread use of pile dwellings in a region subject to frequent overflow. The word "Venezuela" or "Little Venice" is a recognition of this and refers to the pile dwellings once built on the shores of Lake Maracaibo.

What little cultivation is done is effected by means of a stick. Root crops, principally manioc and varieties of sweet potato and yams are cultivated. It is perhaps correct to exclude this area from a discussion of the agricultural area of native America in that such cultivation as is done is more or less desultory and incidental to hunting and fishing. The flesh of monkeys, peccaries, jungle fowls, birds, and snakes, and along the river courses, the mollusks and fish, constitute the principal source of food supply. The American Indian generally does not incline to the use of intoxicating beverages and to the use of habit-forming narcotics, although an intoxicating drink "chicha" made from manioc, palm fruit, fermented maize, bananas, or cacao beans is known to the tribes of this area. The consumption of edible earth or clay is perhaps a degenerate food habit on a par with this form of perversion in dietetics wherever it occurs. The use of tobacco is by means of bone tubes through which snuff is inhaled into the nostrils. The cigar is smoked in the north, while farther south in the Gran Chaco a bowled elbow pipe is used.

Implements and utensils are few and are made of stone, shell, bone, calabash, and other more or less improvised or extemporized materials. As mentioned before, the knowledge of metals had not penetrated the area. Excellent pottery is made, especially by the great stocks, the Arawaks and the Caribs. The Caraya and others make bark cloth like that of Polynesia and middle America. Although the knowledge of weaving and the use of the loom is widespread, bast fiber is also used as a plaiting material. The distribution of carved wood, chiefly in the form of implements and weapons, has

been made the object of comparative study under the hypothesis that here, if anywhere, was an indication of Oceanic influence. Bows and arrows are universal, and the use of poison arrows is general. The famous curari poison is procured from the roots of the *Strychnos toxifera*. The arrow or dart points are of reed or hard wood or bone. In Guiana there is a special weapon known as a blowgun fashioned from a reed or from two hollowed and fitted stems. This is also characteristic of the tribes of the upper Amazon. The darts used in the blowgun are wrapped at their butt ends with slender wads of raw cotton so as to fit the bore of the blowgun. Quivers holding these darts are made of diagonally plaited splint fiber or of bamboo. The wooden clubs of the Guiana Indians in the north of this area are rectangular in section. They are short, made of hard wood, frequently socketed at the operating end with a perforation for the insertion of a polished stone ax head. The spear is in common use, although the throwing stick is rare and limited to central Brazil. The island Carib and Arawak of the West Indies did not use the throwing stick or the blowgun as is frequently assumed. An interesting carry-over in the primitive technology of the people of Amazonia is their method of hafting their polished stone axes. Blades from the Tocantins, crescent-shaped at their cutting edge, have a narrow neck with wings at the butt end. The haft lashing across the bottom of these wings is similar to that of haft lashing on copper axes from upland Peru. The ceremonies in use throughout the area are similar in nature, and among the ceremonial objects is one, the bull roarer, the occurrence of which in central Brazil is reminiscent of similar ceremonial instruments in North America. Urn burials by the Caribs and the Tupí, in which the remains are deposited in large pottery urns, are also similar to practices in middle America and on the Gulf coast.

Students of South American Indians have frequently called attention to the striking culture similarities between selected tribes in the North and South American continents. Similarities in the pottery of the Calchaqui of northwest Argentine and of the Pueblos of Arizona and New Mexico, likewise in the stone chipping and scalping complex possessed alike by the equestrian Apibones of Paraguay and a representative North American Plains tribe, are perhaps more significant than are the semi-interlocking high cultures of Peru and Mexico. A single upland agricultural area based on the production of maize, the potato, the gourd, and the squash, with centers of high divergent culture development in Peru, in Colombia, Central America, and Mexico, is fortified by peripheral cultures removed from one another by thousands of miles of intervening tropical woodlands but preserving in many respects a cultural iden-

tity. The development of irrigation in connection with dry upland valley agriculture, for example, extends all the way from the Pueblo southwest to Peru.

Not a single plant has been discovered by European or Negro immigrants the properties of which were unknown to Indians occupying the area, and not a single additional animal species has been domesticated by these later immigrants whose qualities were unknown to the Andean South American tribe inhabiting that area. The upland tribes developed the cultivation of the potato, cinchona, coca, along with maize and cotton, which were cultivated in Central America as well. The effect of the practice of using the llama as a pack animal and of herding the wool-bearing alpaca was far-reaching. The further development of metal working to the stage of welding and alloying, though significant, was not as important as such mental achievements as the invention of the decimal counting system based on use of quipus, which resembles very much the well-known Chinese abacus. Each of the several inventions discussed must have been first used in South America because of their entire absence either in North America or in any part of the Old World. Furthermore, they are for the most part restricted in use and distribution to Amazonia or to the Andean uplands. Few of these discoveries made by native South American Indians have spread to the North American continent. The language of the Arawak carried from its most northerly outpost in Cuba and the Bahamas to the coast of Florida was accompanied by several Arawak inventions pertaining to the manufacture of flour from roots, to the carving of wooden seats, and to a limited extent in the shaping of polished stone implements—the celt and the monolithic ax, and in pottery forms and designs. Here we are on uncertain ground and cannot definitely cite the exact point of origin for traits having a Caribbean distribution including Central America. On the other hand, certain culture traits of southern South America resemble those of temperate and northern North America. These include the wearing of skin clothing, the chipping of stone weapon points, stone boiling, and the use of the sucking tube. The absence of these traits in Amazonia is not to be explained as proof that the peoples living in the Amazonian backwash were of Oceanic origin, but simply as illustrative of traits not suitable to a tropical people.

Other generally distributed traits, such as the use of the digging stick, the bone awl, fire-drill apparatus for fire making, ear plugs, the spear thrower, bow and arrow, the knobbed-head bird arrow, the spear, the harpoon, and fish nets are useful alike to fishing, hunting, and agricultural tribes throughout America. It is not at all unlikely that such tribes as have departed farthest from the

general basic American Indian trait complex, which is based on a temperate or nontropically humid environment, would do so in a tropical rain forest climate such as Amazonia regardless of whether the tribe entered South America by way of the Panaman Isthmus or the Antilles.

In tropical eastern South America appear sporadically among the Botocudo, Maku, Guayaqui, and others such typical North American traits as pemmican, twined and coiled basketry, pit ovens, water-tight baskets, the platform bed, sandals, feathered and stone-tipped arrows. However, throughout the greater portion of Amazonia these traits are replaced by inventions more applicable to the environment, such as bone or wood arrowheads instead of those of chipped stone, and the hammock instead of the platform bed, clay containers instead of the water-tight baskets, the cigar or snuffing tube instead of the tubular pipe. Even the tempering of pottery with bits of coral or sponge spicules speaks of a ready adjustment to a new environment.

Today one of the most startling resemblances of South American culture to that of North America lies in the chipped arrow or spearhead and skin scrapers in those areas in temperate South America where stone suitable for chipping is plentiful and where its use in the preparation of skin robes remains desirable. These culture traits, appearing sporadically in tropical eastern South America are of common occurrence in southern and temperate portions of the continent.

It is impossible to determine whether the several linguistic stocks present in South America indicate separate immigrations from the North American continent. The Chocó language penetrates southeastern Panama, and the Cuna, another Colombian linguistic stock, extends somewhat farther into the Isthmus. Neither of the Carib and Arawak stock languages of the Guiana, Venezuelan, and West Indian area extend beyond the Caribbean except as Arawak words were carried into Florida by sporadic Arawak visitors. Whence then the number of unrelated language stocks in South America? Words do change in the course of time, but differences in grammar involved in the several existing linguistic stocks of South America must have a significance as yet not fully realized. This is especially the case in that there appears to be not the remotest connection with any of the equally distinct North American linguistic stocks or with those of Oceania.

An interesting observation lies in the fact that in Amazonia are tribes sharing similar environment but possessing varying degrees of enlightenment. The long-headed peoples (dolichocephalic) of eastern South America are in a manner less progressive than their

broad-headed (brachycephalic) neighbors. The attempt has been made to establish a chronology placing such long-headed tribes earlier than the broad heads. The Botocudos of Brazil and the Ciboneyes of the Greater Antilles are typical of the former. The forests separating the Panaman Chiriqui high culture from the Chibcha-Colombia center served as a filter or even as an effective stopper once the earlier migrations had passed. Once the high cultures of Central America were developed, a certain stagnation in migrations must have effectively shut off the passing of migratory hunters and gleaners across the Isthmus. The nomadism of American tribes ceased in every area once they become agriculturists, hence communication ceased.

Later developments in temperate and Arctic North America did not penetrate South America. Most of those inventions or culture traits borrowed bodily from Asia are late. Included among these are the use of the toboggan and the sledge, the sinew-backed and compound bow, decorative work effected with split porcupine quills, and others not in use by South American tribes today. The use of the dog for drawing burdens, the dog travois, may have been known to early South American immigrants and may have supplied the basis for the use of the llama as a beast of burden. Of this we are not certain. The Arawak employed the dog as a guard, also bred it for use of its meat as food.

The invention of the rubber enema syringe is but one of the many contributions of South American tropical tribes to the knowledge of the uses of rubber and of drugs, narcotics, and medicinal plants generally.

When European explorers first penetrated Oceania they found domesticated chickens and pigs and certain plants in widespread use. In pre-Colombian times the Indians of tropical South America had no knowledge of such accessories to Polynesian culture. Taro also was known to Oceanic peoples but not to South American Indians, although it is now extensively cultivated in eastern Brazil. The sweetpotato is but a late arrival in the economy of tropical America. The fact that Polynesian voyagers carried with them in their journeying samples of their cultivated plants is indicative of the fact that they did not frequent the South American coast or the economic plants known to them would have been found growing by the Spanish explorers. Tortoise shell is widely used by Polynesians, and although tortoises are fished on the Pacific coast of Panama, the shell is not used in the handicrafts. In the same manner, regardless of the possible existence of coconut palm on the Pacific coast of tropical America, Indians did not include its use in their primitive technology. The

outrigger canoe, of wide-spread use on the Pacific was unknown to tropical American Indian tribes.

The strange similarity in the use of calabash containers for lime chewed with coca leaves with the Melanesian use of similar containers for lime chewed with betel nut is perhaps after all but a coincidence. A spoon stopper for extracting the lime from the container is used in both areas. In the North American northwest the practice of chewing lime with tobacco has been noted. Pan's pipes in Peru appears with early Nasca pottery but apparently is of much later occurrence in Oceania. The stilt house, fire drill, nose flute, hand censer, teeth inlay, bark beaters and bark cloth, the pellet bow and the blowgun, all have a remarkable parallel development in South America and in the East Indies.

The venesection bow of the Gês tribes of eastern Brazil and also of the Cuna of southeastern Panama has a convergent type in Oceania, whereas the wooden seat of prehistoric Florida, of the Amazonian Arawak, and of the Polynesian Tahitians has an independent origin in the two areas. Similar pseudo-Polynesian inventions used by the Chocó are the legged wooden pillow, and leg-supported wooden bowls. To assume the transition from leg-supported pottery vessels and from leg-supported stone seats and metates to wooden leg-supported bowls, seats, and pillows is more plausible than to attribute such objects to Polynesian origins.

The presence of secondary urn burial and cremation in connection with endocannibalism in southeastern North America and Amazonia is worthy of mention along with such commonly shared traits within the two areas as artificial head deformation, wooden seats, and the preparation of manioc flour in Amazonia and coonti flour in Florida.

In the Antilles and in southeastern United States at the time of the first European contacts, metals were used, but the metal-working techniques were elementary. Cold hammering, not casting, was the method employed in shaping. Alloys of gold, copper, and silver were obtained through trade. Intentional alloying to produce bronze is an invention of upland Andean culture, as are also the tools such as the pincers used in working cast and alloyed metals.

Various methods of hunting, as for instance, from a calabash blind, are common alike to ancient West Indian Arawak, Amazonian Mojo, and Chinese practice. It is absurd to propose a carry-over of this hunting practice from China to eastern tropical America.

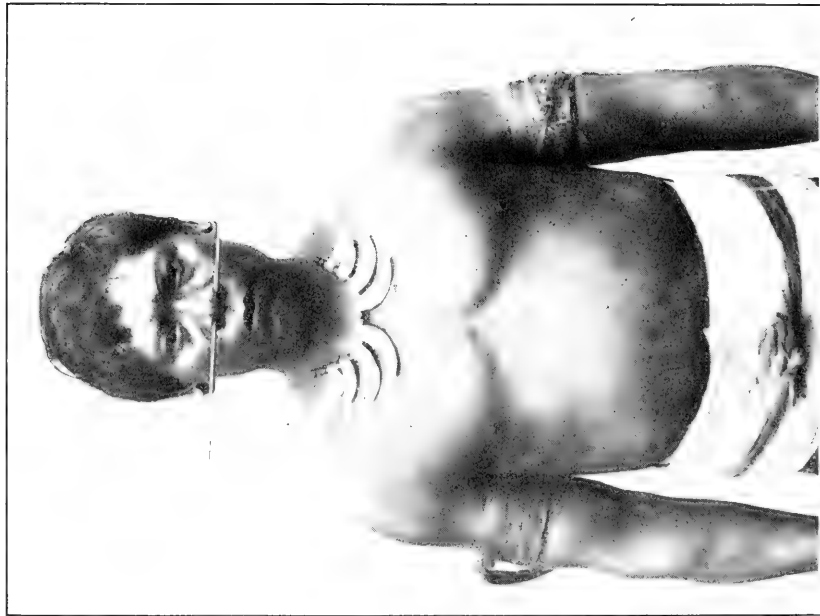
There are other interesting parallels in culture traits ranging from the quilted armor of Peru, Yucatan, Borneo, and North Africa; batic design on textiles from the Peruvian coast and Java; the balance-beam scale of Peru and India; the rope ferry ("uruya") of western South America and the Himalayan Tibet; double rafts of inflated

animal skins of northern Chile and western China; human excrement manures from Mexico, Peru, and China and Japan. Other similarities in Old and New World cultures have to do with such widely diverse traits as lacquer, mirrors, stamps and block printing, inlay of teeth, embalming of the dead, and many others. Many of these Asiatic culture traits appear both in Peru and Mexico or Central America, others occur only in South America. The fact that these traits do not all appear in one area of the Old World, but occur one in Java, another in Himalayan Tibet, another in Egypt, still others in China or in central Asia, requires a rather complicated thinking process to bring them all to a focus in Peru and Middle America or Amazonia. When one includes in the comparative table architectural details, pottery, or metallurgical ages, the search for similarities and identities takes one still farther afield. Japanese neolithic pottery, Egyptian pyramids, Chinese and Scythian bronzes complete the mosaic leading one to suppose that "Lo! the poor Indian" has become heir to all the ages. Strangely, he just missed inheriting the potter's wheel, the bellows, glazing, kiln-baked brick, the vehicular wheel, stringed musical instruments, the handmill with a turning handle, attached rudders (Peruvians had sails), and the mason's arch. Contrasted with these omissions are the large number of food and medicinal plants and the smaller number of domesticated animals, the use of which undoubtedly began in America. The conclusion is obvious, namely, that the high cultures of America, like the more humble Amazonian tropical woodland centers, are the products of a long period of local development entirely independent of Asiatic or Oceanic influence, not to mention that of the African Negro.



MACUNA (LEFT), YABAHÁNA (RIGHT).

These tribes live on the Rio Apaporis which is a tributary of the Yapura, a tributary of the Upper Amazon, western Brazil. To be noted are the heavy blowguns and tubular quiver, also the absence of clothing except for wide ligature-like belt, ornamental arm band, and stick piercing nasal septum.



1. YABAHANA INDIAN, RIO APAPORÍS, WESTERN BRAZIL.
Typical garb showing pierced nasal septum, discoidal ear plugs, arm ligatures, bast fiber belt, and necklace of teeth.



2. CAMPA INDIAN, PERU.
From an oil painting, U.S.N.M. no. 16466, W. E. Safford collection.



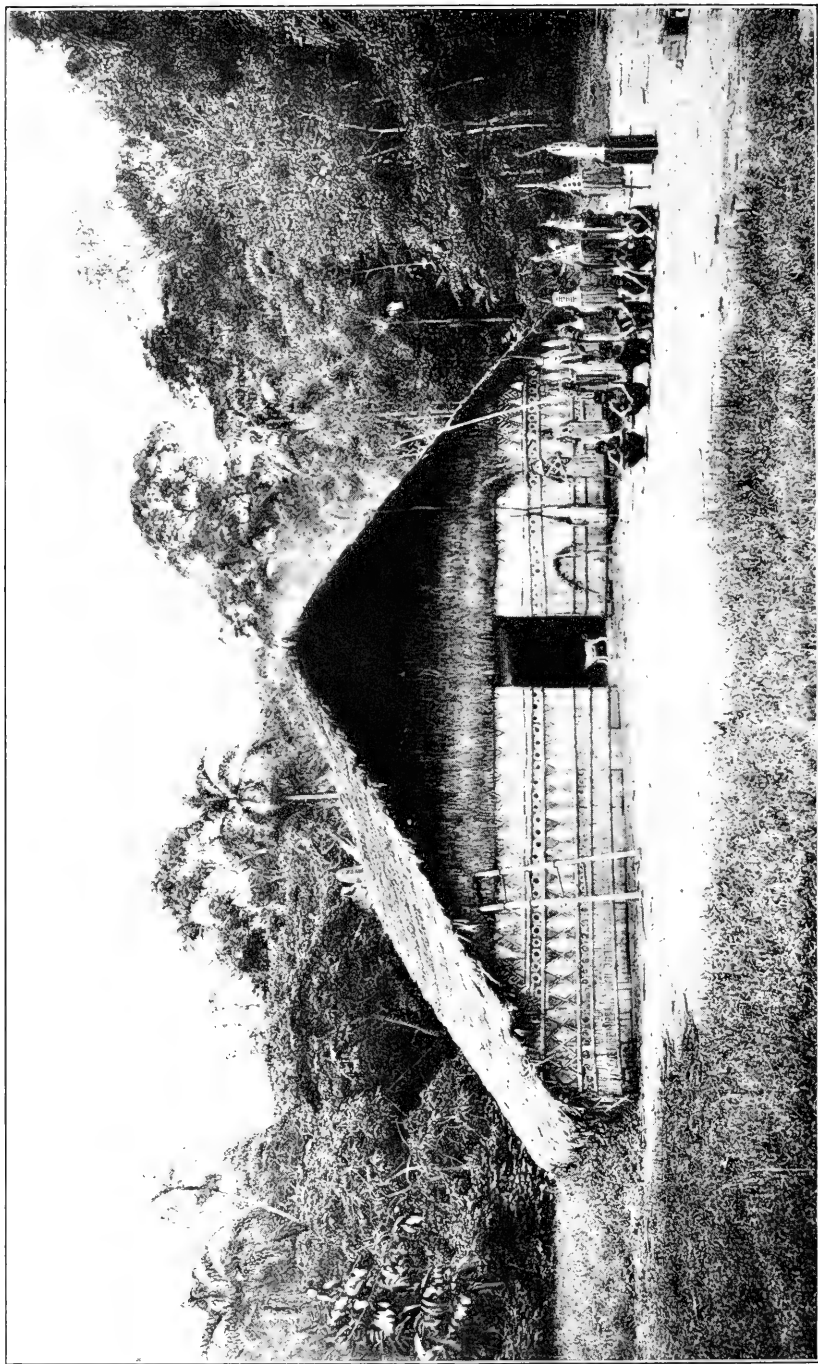
1. CASHIBO INDIAN WOMAN. UCAYALI RIVER. EASTERN PERU.

From an oil painting, U.S.N.M. no. 164636, W. E. Safford collection.

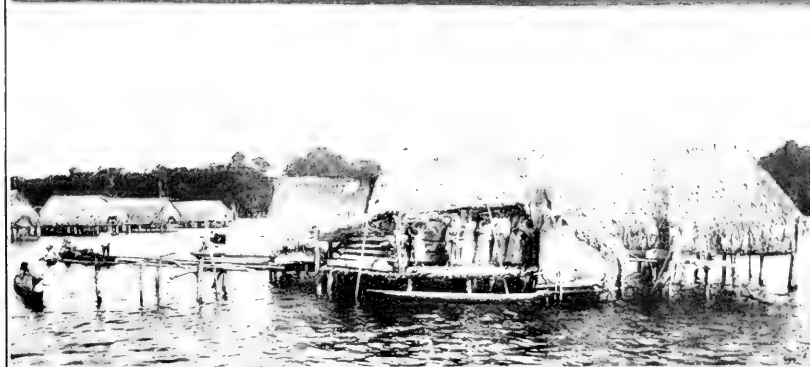


2. CUNIVO INDIAN. UCAYALI RIVER. EASTERN PERU.

From an oil painting, U.S.N.M. no. 164612, W. E. Safford collection.



COMMUNAL HOUSE OF THE KÁUA INDIANS (ARAWAK STOCK), RIO AIARÝ, NORTHWEST BRAZIL.
The painted panels on the front wall, also the large dance masks beyond the squatting men on the right, characterize their art.



1. THATCHED TIPI OF THE BORORO INDIANS, MATTO GROSSO, CENTRAL BRAZIL.
2. MODEL OF A CIRCULAR COMMUNAL HOUSE AND ENVIRONS, CARIB INDIANS, GUIANA.
3. PILE DWELLINGS OF THE GOAJIRO INDIANS (ARAWAK STOCK) ON LAKE SINAMARIA, SOUTH OF MARACAIBO, VENEZUELA.

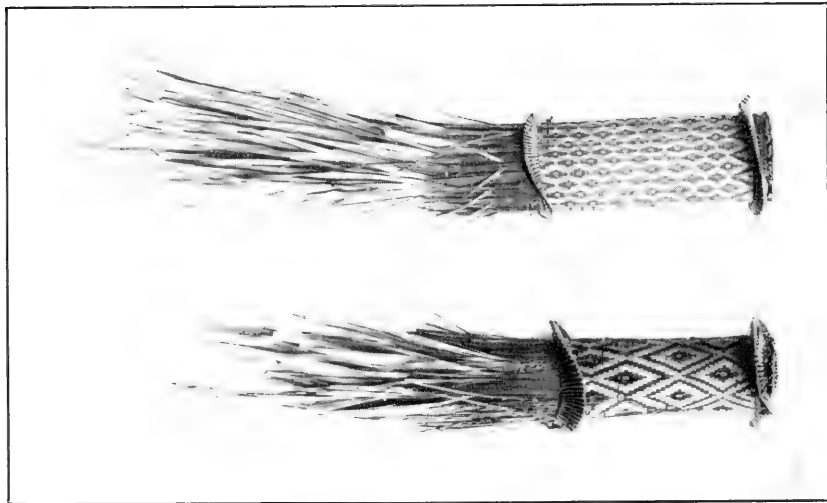


HEAD TROPHIES (LEFT-RIGHT) OF THE MUNDRUKÚ INDIANS (TUPI STOCK) ON THE TAPAJOS RIVER; SOUTH CENTRAL BRAZIL, AND OF THE JIVARO (CENTER) OF EASTERN ECUADOR.

The motivation and treatment of head trophies by these widely separated tribes is quite distinct.

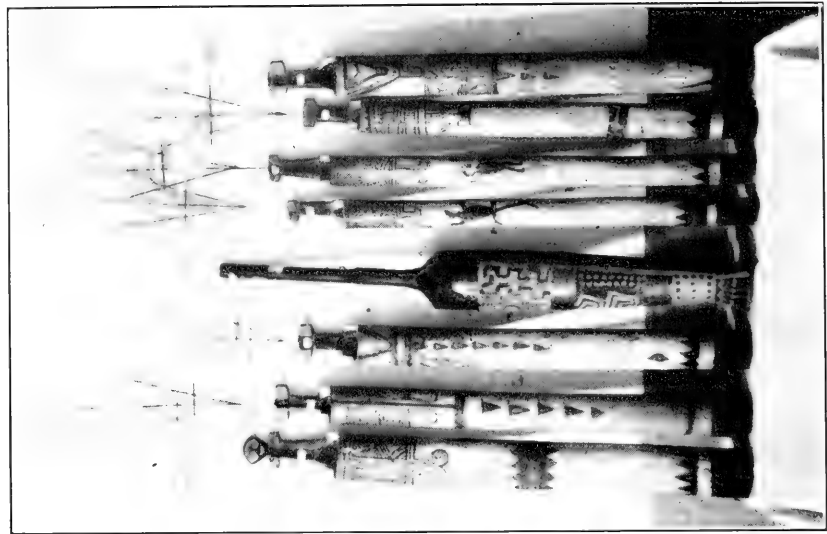


CADIUÉO (LEFT AND CENTER) AND CHAMACOCO (RIGHT) INDIAN GIRLS OF THE NABILEQUE RIVER AREA, GRAN CHACO, PARAGUAY
The elaborate painted designs on body and face are characteristic of these Guaycuru tribes.

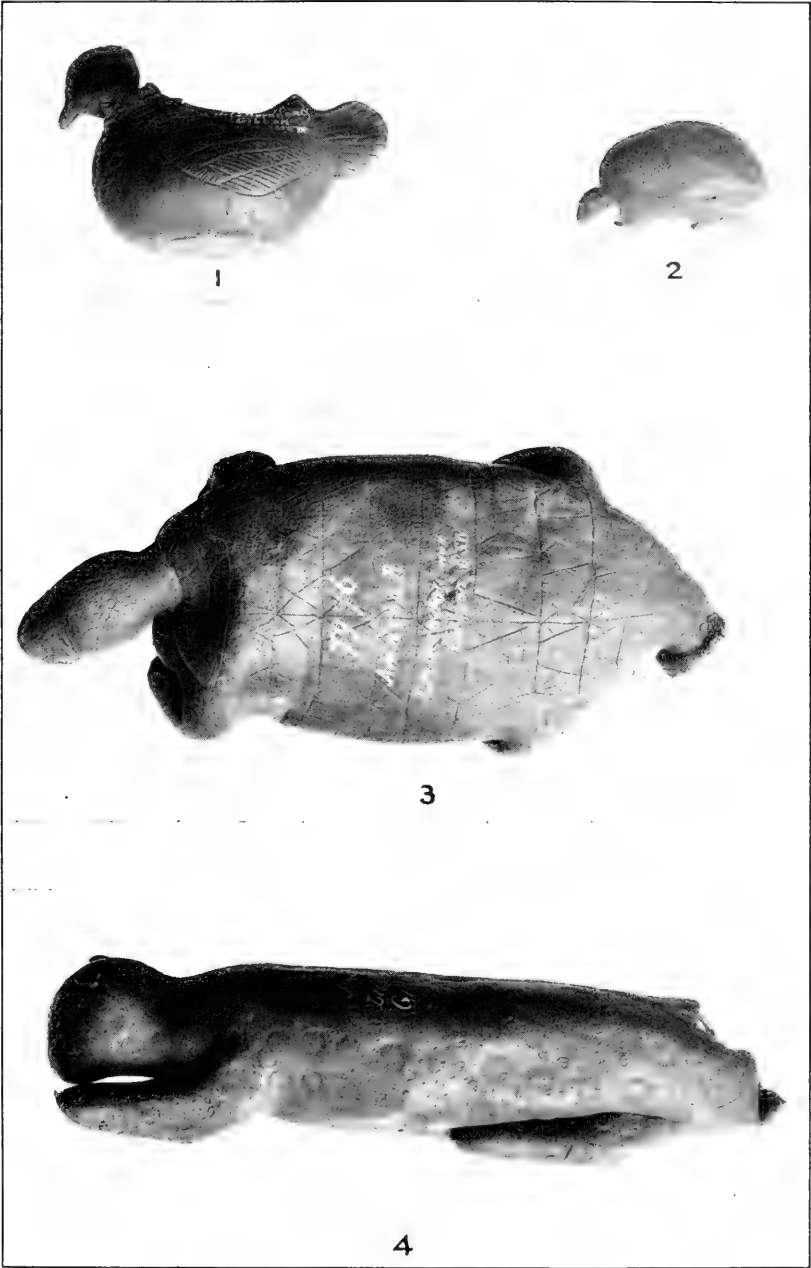


1. TORTOISE GLOVES OF THE MAHUÊ (TUPI STOCK).

U. S. N. M. nos. 499-500, collected by Lds. Herndon and Gibbon in 1851. These gloves, which might be called hymeneal bracelets, are filled with venomous *Toxopneustes* and the initiate must endure without flinching the torture of their sting before he can take a wife.

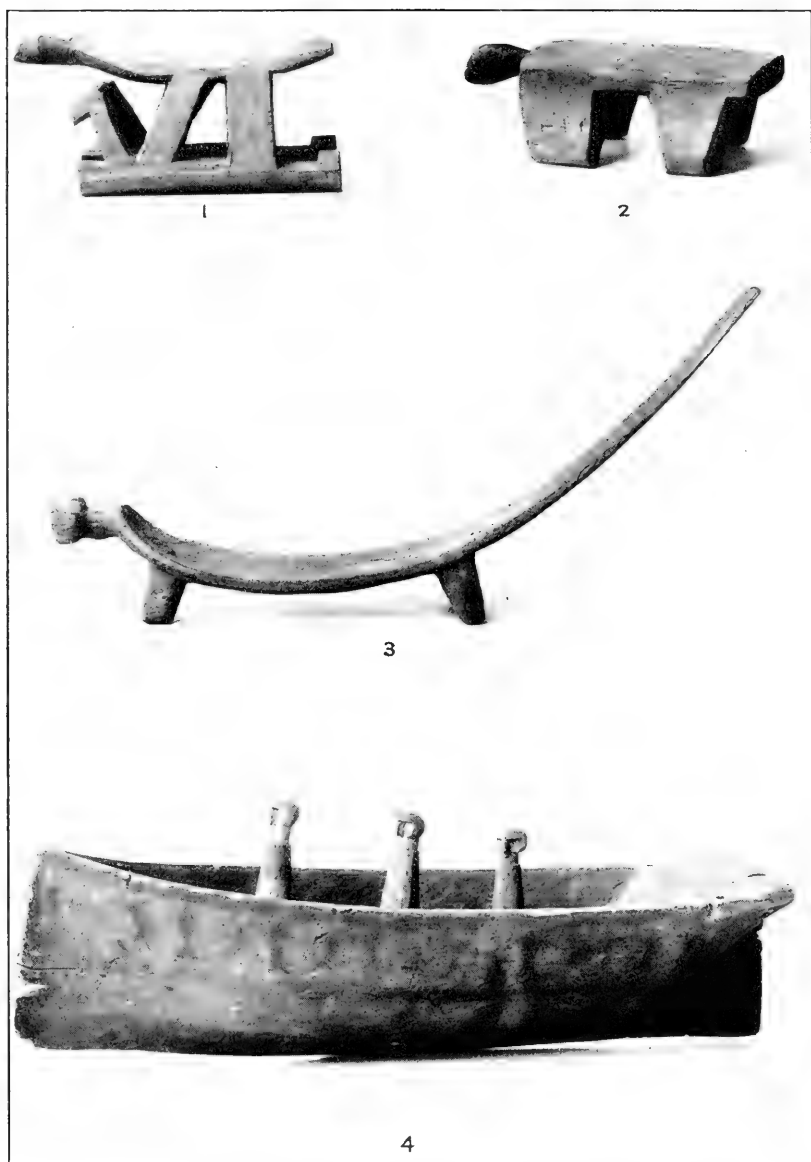


2. MEN OF THE WANANA INDIANS OF THE UAUPE'S RIVER, NORTHWEST BRAZIL, USE THESE CECROPIA WOOD STAMPERS DECORATED WITH CHARRED DESIGNS AND FEATHER WANDS IN BEATING TIME TO THE DANCE.



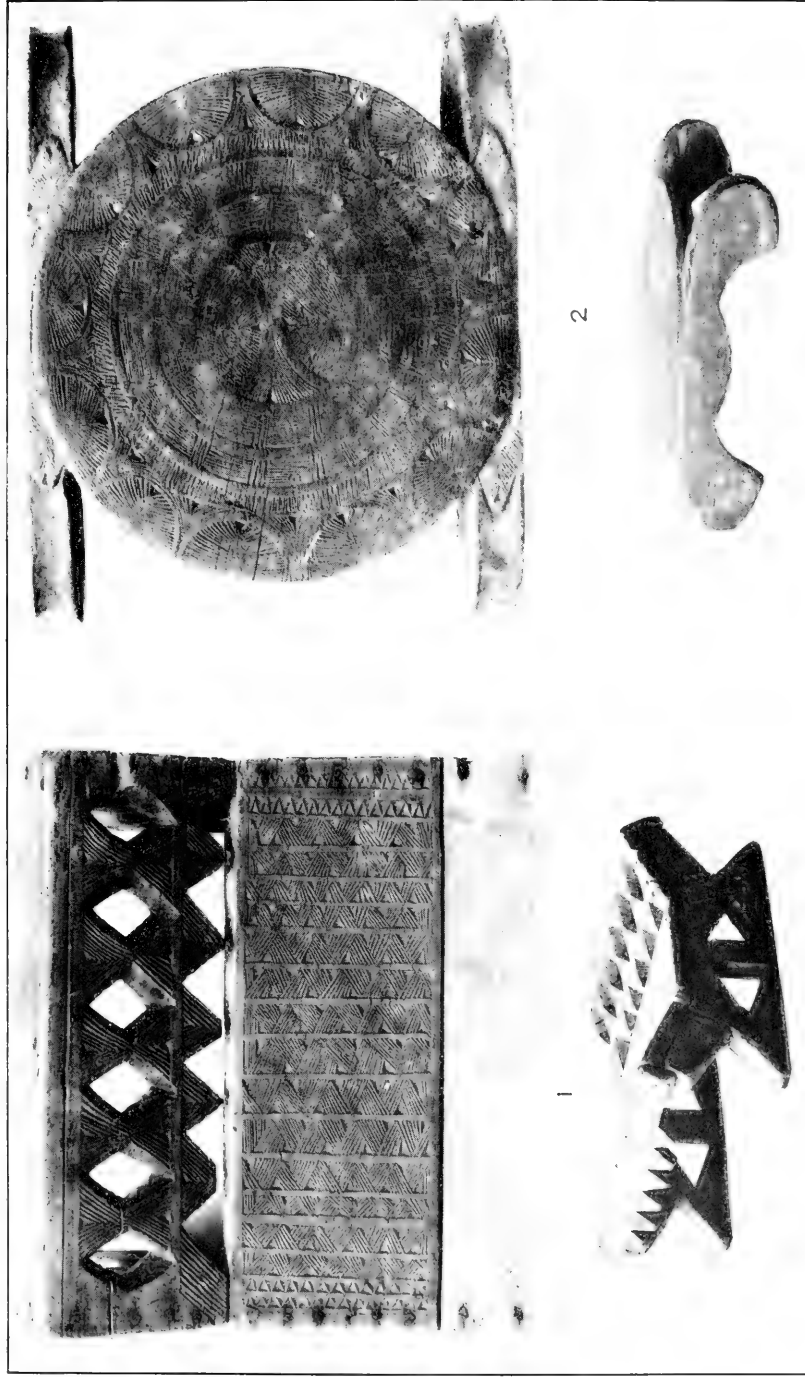
ANIMAL FIGURINES FROM AMAZONIAN TRIBES COLLECTED BY LTS. HERNDON AND GIBBON IN 1851.

U.S.N.M. nos. 7976-7979. 1, Chicken; 2, armadillo; 3, tortoise; 4, jaguar.



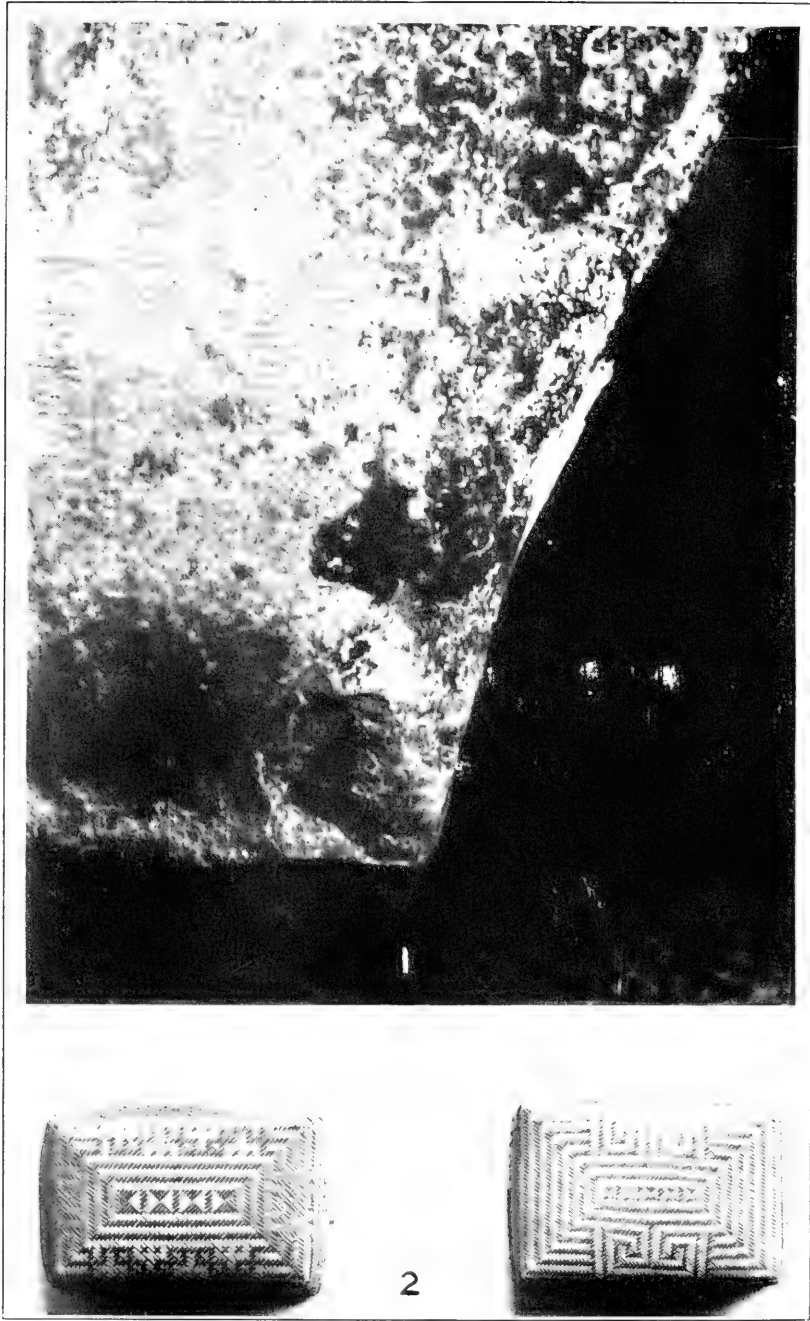
CARVED WOODEN SEATS AND WITCHCRAFT PARAPHERNALIA.

- 1, Animal form (praying mantis), Makusi (Carib), British Guiana, U.S.N.M. no. 291727; 2, simple form, Talamanca, Costa Rica, U.S.N.M. no. 15461; 3, hammock form, Arawak, Turk's Island, West Indies, U.S.N.M. no. 30053; 4, boat for making witchcraft used by medicine man of the Choco, Upper Atrato River Valley, U.S.N.M. no. 362522.



WOODEN SEATS CARVED BY THE BUSH NEGROES OF THE UPPER ATRATO RIVER VALLEY, COLOMBIA.

U.S.N.M. nos. 362524-5, W. A. Archer collection.



SIMILARITY IN ARAWAK DESIGN.

1. Petroglyph in the cave known as "La Güacaca del Comedero", Cotuí, Dominican Republic; 2, woven design in twilled basket, British Guiana.

COMMERCE, TRADE, AND MONETARY UNITS OF THE MAYA¹

By FRANS BLOM

INTRODUCTION

On his fourth voyage Columbus reached the Bay Islands in the Gulf of Honduras, and while his brother, Bartolomé, was sent ashore to explore the island called Guanaja, Christopher saw coming from the west a large dugout canoe, manned by 25 Indians. Over the center of the canoe was a canopy, under which was seated the owner. The rowers came alongside the admiral's ship, and he had the natives—men, women, and children—brought aboard.

They were timid and proper people, because when one pulled their clothing they immediately covered themselves again, which gave great satisfaction to the admiral and those with him. He treated them with great kindness, and presented them with some objects from Castille in exchange for some of their strange-looking things, to take with him in order to show what kind of people he had discovered. * * * (Columbus, Bartolomé, in HARRISSE, 1866.)²

The canoe was 8 feet wide. They had in it much clothing of the kind which they weave of cotton in this land, such as cloth woven with many designs and colors, shirts which reached the knees, and some square pieces of cloth which they use for cloaks, calling them *zuyen*; knives of flint, swords of very strong wood with knives of flint set along the edges, and foodstuff of the country. (Oviedo y Valdes, 1851, 1853.)

They had copper hatchets also, and little bells made of the same material, beans of cacao, which they prized highly, and a fermented drink of maize.

The admiral had a long conference with the chief of the natives, apparently a merchant of importance, and he learned that to the west was a great land called "Maïam" or "Yucatán." These natives were of higher culture and better equipped than those encountered by the Spaniards on the islands of the West Indies.

¹Address to the joint session of sections H, K, and I, of the American Association for the Advancement of Science, meeting at New Orleans, December 1931. Reprinted by permission from Middle American Research Series, Publ. no. 4, "Middle American Papers", the Tulane University of Louisiana, 1932.

²Names and dates in parentheses refer to bibliography at end of paper.

They were Maya people, as indicated by the name of their provenience as well as by the word which they used for their cloaks, i. e., zuyen. In the Motul dictionary (1929) of Maya and Spanish we find such cloaks called zuyem.

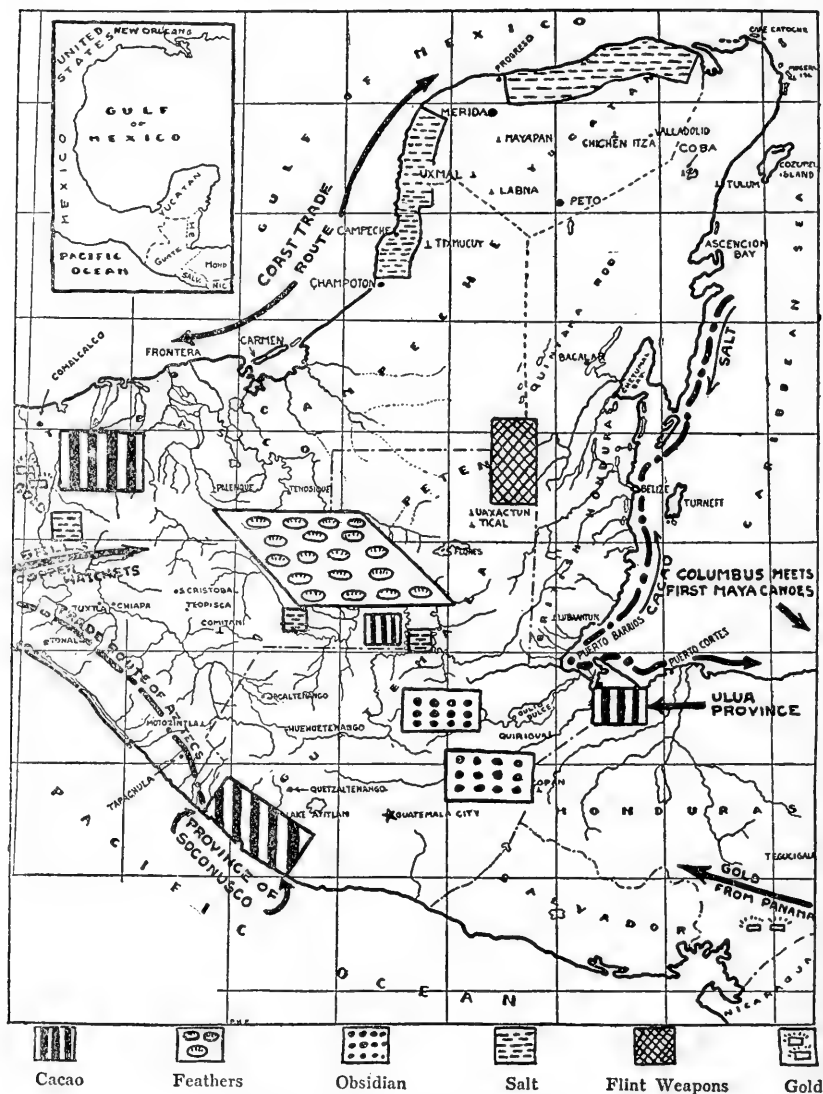


FIGURE 1.—Trade map of the Maya area.

It is interesting to note that the very first contact which the Spaniards had with the Maya people was with a trader.

Bartolomé Columbus' statement furthermore informs us that the merchandise was cotton cloth, copper hatchets, and bells, as well as

cacao beans, "which they prized highly." From the very beginning we are confronted with merchandise and money.

COMMERCE, TRADE, AND MONETARY UNITS

In order to give a picture of Maya trade it is obvious that first of all we must understand Maya needs. Our sources of information are the books written by the Conquerors, such as Bernal Diaz' "True History of the Conquest of New Spain" (1632, 1904) and the reports written by the Conquerors who had received land grants from the king, in answer to royal questionnaires dated 1579 and 1581, and embodied in the two volumes called "Relaciones de Yucatán" (1898, 1900).

Next comes a group of writings by the clergy, foremost among which stands Diego de Landa's "Relacion de las Cosas de Yucatan" (1864) and several of the works of Las Casas (1909), and then certain contemporaneous second-hand information, such as the narratives of Peter Martyr and others.

Finally, we have archeological, geological, and botanical evidence gathered in recent years.

Our sources on the Maya are scant, and in order to give complete pictures we must now and then draw upon our knowledge of the Aztecs.

The staple cereal of the Maya as well as of most other American Indians was maize or corn (*ichim*). This could be produced in all parts of the Maya area, and only became an object of trade when drought or floods created a scarcity in certain sections. Next in importance followed black beans (*buul*), peppers, calabashes, and gourds (*bush*). The gourd was used as a drinking cup. It grows on a tree. The calabash is a creeper, and its dried fruit was and is used for larger vessels. Certain types of gourds are used for water bottles today, just as they were in ancient times.

Salt is a most important ingredient. We do not realize its extreme importance until we are without it. As salt was produced only in limited areas, it naturally became a major trade object. In the Maya area salt was produced chiefly in the salt marshes which lie along the northern and western coast of Yucatán from Campeche to Cape Catoche. These marshes were common property of the nations living along their edges, and huge quantities of salt were produced by sun evaporation, and traded to the south.

In the south several natural salt wells are found, as also in the Tabasco and the southern Vera Cruz region. These wells are geological features, often associated with oil-producing salt domes.

In the highlands of the Maya area we encounter salt wells at Ixtapa³ in the State of Chiapas, at Salinas on the Chixoy River⁴ in Guatemala, and a few other places. But this production was small and very localized in distribution.

Game, such as deer, wild hog, and turkey was abundant; and the sea, rivers, and lakes gave fish in plenty.

Sweetening was derived from honey. The Central American bee is stingless, and most honey was gathered in the forests, though we do hear of large shelters in which hollow logs are stacked as beehives (Davila, in Oviedo, 1851, 1853). There must have been an extensive trade in this commodity, because the Spaniards considered honey one of the things in which tribute could be paid. The byproduct of honey, wax, was also a merchandise and may have been used in pre-Columbian times for candles. Today we find that the tribes living in the remote parts of the Maya area make beeswax candles, and that black candles are particularly favored as offerings to the ancient gods.

From Bartolomé Columbus' report we learn of an intoxicating drink made of maize, and from the conquerors we hear of the famous drink called "balché" made of the bark of a certain tree, and quite intoxicating. The most favored beverage, though, was cacao or chocolate.

Almost none of our informants fails to mention the cacao (cocoa, *Theobroma* L.) bean as the ingredient for a drink, but in particular they speak of it as being the monetary unit of most of the Middle American peoples: Aztec, Maya, the inhabitants of Nicaragua and Panama, all used this bean as their monetary basis, to the amazement of the Spaniards, who were driving through these countries looting and killing to enrich themselves on their own monetary units, gold and silver.

Oviedo gives us a lengthy statement about the cacao-bean money, and though he speaks of Nicaragua, we will show through other quotations that this coin was in such general use that it is likely that his statement holds good for all countries, from the valley of Mexico to Panama.

In the "Historia General y Natural de Indias", Libro 8, Capitulo 30 (edition 1851, vol. I, pp. 316-317), we find the following statement concerning cacao beans, or "almonds", as Oviedo calls them:

³ Istac, the Nahuatl word for white or salt; apan, water.

⁴ Pinelo, Leon. Relacion * * * sobre la pacificación y población de las Provincias del Manché, 1 Lacandon, etc. 1639. "In 1625 the Father Francisco Moran penetrated to a place called: 'Bolontehuitz', which is the same as Nine Mountains, where he discovered a stream, which running into some flats, forms a great salt mine, unique and singular in all that land of the Ah-Itza."

They guard them and hold them in the same price and esteem as the Christians hold gold or coin; because these almonds are regarded as such by them, as they can buy all things with them. In the way that in said Province of Nicaragua a rabbit is worth 10 of these almonds, and for the price of 4 almonds they give 8 of that excellent fruit which they call "munoncapot" (the chicotl-zapotl, or *Achras zapota* L.), and a slave costs 100 almonds, more or less, according to his condition and the agreement between the seller and buyer. And because they in that country have women who give their bodies for a price, just as the public women among the Christians, and who live from this (and such women are called guatapol, which is the same as to say prostitute), he who wants them for his lustful use give them for a run 8 or 10 almonds, according to how he and she agree. I want to say, therefore, that there is nothing among these people, where this money circulates, which cannot be bought or sold in the same way in which good doubloons, or ducats of two, circulate among Christians.

And even in that almond money one finds falsifications, in order that one may cheat the other and mix fake pieces among a quantity of the good ones. These false pieces are made by removing the bark or skin which some of the beans have, just like our almonds, and filling them with earth or something similar, and they close the hole with such skill that one cannot see it. In order to beware of this falsification, he who receives the almonds must revise them one by one when he counts them, and place his first finger or the next one against his thumb, pressing each almond, because even though a false one is well filled it can be felt by the touch to be different from the real ones.

From these almonds the rulers and the rich make a certain drink * * * which they hold in high esteem; and it is only the great and those who can afford it who use it, because the common people can neither afford nor think of pleasing their palate with this drink; because it would be nothing less than to make themselves poor and drink money or throw it somewhere where it would be lost. But the lords calachunis⁶ and principal men use it, because they can afford it, and tribute is paid in this form of money or almonds, and they furthermore harvest it themselves and inherit it.

This is a definite explanation, backed by innumerable other statements less elaborate but to the same effect.

The King of Spain sent out a questionnaire to all those of the Conquerors who had received land grants in payment of their services. In 1579 and 1581 the so-called encomenderos of Mérida and Valladolid answered these, and question 33 relates to trade. Practically every one of these answers speaks of cacao brought from Tabasco and Honduras as money.

Money, i. e., Spanish coin, was scarce in the New World, and we have definite statements to the effect that both Cortés, conqueror of New Spain, and Montejo, conqueror of Yucatán, were forced to pay their troops in cacao beans. Oviedo, as quoted above, shows us that you could buy a rabbit or a prostitute for 10 beans, and that a slave would cost 100 beans in Nicaragua, where this form of money was scarce, because it was a great distance from its source of produc-

⁶ Calachuni. This word is found in many records. Bernal Diaz gives it as a war cry during the "Mala Pelea" in Campeche. Cardenas uses it, as well as Oviedo.

tion. This indicates that the cacao bean was an established unit of exchange among those people: just as established as our gold standard, which can only hold its own as long as it is accepted at an agreed value, as proved by recent happenings.

In Mexico, on the other hand, the native carriers were to be paid 100 beans a day. There the Spanish government valued from 80 to 100 beans to a real, which was an eighth of a peso. A *carga*, which was a burden of 2 arrobas, or 50 pounds, could be bought for from 30 to 28 pesos.⁶

Thus a beverage and a monetary unit are closely linked. The international monetary unit of Aztec, Maya, Chorotega, and other nations in Middle America was the cacao bean. Its value fluctuated according to supply and demand, but it was a standard unit nonetheless.

While we are speaking about the monetary unit, we may just as well speak of the counting of this unit.

We have a decimal system. We count units to 10, and then in multiples of 10.

The middle Americans had a vigesimal system. They counted in units to 20, and then in multiples of 20.

Their system of numerals had a dot for 1, two dots for 2, three dots for 3, four dots for 4, and a bar for 5. Two bars and three dots make 13.

When we reach 9 we move one position over to the left, reaching 10, which is one with our sign for nothing. Reaching 99, we move one more place to the left, getting 100, and so on and so forth, towards the left, ad infinitum, rising in numerical value by multiples of 10.

The Maya counted in twenties, and from the inscriptions carved on the surfaces of limestone monuments and entries in their books, painted on fiber paper, we know that their count was in columns, with the lowest value, the unit, at the bottom, and rising toward the top; but read from the top down, just as we have our lowest value to the right, rise by multiples of 10 moving toward the left, but read from left to right. The units are at the bottom of the column, and these units reached 19, or 3 bars and 4 dots. Just as



FIGURE 2.



FIGURE 3.



FIGURE 4.

⁶ Suarez de Peralta, pp. 166-167, 1878. If we take 100 beans multiplied by 8 (8 reales to a peso) we get 800 beans. The price of a *carga* is 30 pesos, which gives 24,000 beans, or three times the Maya count of 8,000; or 20 times 400.

we move over when we reach 9, so they move one up when they reached 19. Their count is as simple as ours. A single dot in the second position up in the column signifies 20, and a certain sign, probably a shell, signifies 0, zero. In our decimal annotation it is 9; next comes one followed by zero, 10.

In the Maya vigesimal annotation it is 4 dots, 3 bars, 19 (fig. 2). The next move will be 20 (fig. 3). Figure 4 shows the sign for 26.

The count was in twenties and multiples of twenties, thus:

Hun-----	1
Kal-----	20
Bak-----	400 (20 by 20)
Pic-----	8,000 (20 by 400)
Cabal-----	160,000 (20 by 8,000), etc., etc.

This was the count for such objects as canoes, warriors, paces, and monetary units.

We are now familiar with the basic monetary unit and with the method in which it was counted. It happened also to be a food product, and therefore we digressed to this and also to the system of counting. Now we return to the commercial needs of the Maya.

Our records show that there was a large demand for medicinal herbs, some of which grew in the highland pine forests, and others of which were to be found in the humid coastal swamps. Therefore, there must have been trade in medicinal herbs, both such as had actual curative properties and those which were imagined to heal. We find not only that plants were used as medicine, but so also were animals and gums. The cacao peel was considered a great curative for cuts, the resin of the pine tree as well as turpentine were healers, as was also the resin of the tree which produced copal gum, or "pom" as it was called by the Maya. Chicle, from the chicotl-zapotl, was not only used for healing but was also chewed, in a truly American fashion.

These tree gums bring us to another line of trade. The "pom", the chicle, the sap of the rubber tree, and other matters of resinous substance were sought as incense to be burned before the gods, and while we speak of these resins and gums, it might be permissible to draw attention to Melchor Alfaro's map of the State of Tabasco, a truly remarkable map for its time, where are indicated some "springs where issues a water which curdles in the sun and forms a black resin, with which one can glue things—there are similar ones in other parts of the province." This map was made in 1579, and to my knowledge this is the first mention we have of oil-seepages.⁷

⁷ Published in *Relaciones de Yucatan*, vol. 2, and Maudslay's edition of Bernal Diaz, vol. 3.

The Maya as well as the Aztec were ardent ball players; the pok-ta-pok or tlachtli game was attended by thousands, and it was played with balls made of rubber. This was produced in the tropical lowlands, and therefore there was an extensive trade in this commodity. We read that 22 Olmeca towns in the lowlands of the Gulf coast paid 16,000 rubber balls in tribute to the rulers of Mexico.

Rubber was grown exclusively in the tropical lowlands and brought to the highlands of Mexico by traders. These traders were probably Maya, for in the Maya language we find the word "uol", "uolol" denoting a ball or round thing from which the Nahuatl derived the word "ollin" for rubber and the Spaniards, still later, their word hule.

Next we come to the Maya utensils. In the house for cooking purposes they needed containers and grinding stones on which to prepare their bread, the maize pancake called "tortilla" today. The containers were varied, some made of gourds, some of clay, and others of stone. The gourd containers could be grown throughout the area, and clay for pottery containers was abundant in all parts.

But there is a difference between utensils and art pieces. Man needs utensils for household purposes, and through the centuries he has shown a desire for objects of beauty, to be used only on special occasions. This desire to celebrate special events is the mother of art.

Utilitarian vessels for use in daily household tasks were produced on the spot, but certain towns or regions developed specialties in the potter's art, which, because of their peculiarity, or peculiar beauty, became famous and desirable. Therefore, they became trade objects.

As far as the household needs were concerned, the natives obtained their pots and pans from the gourd tree in the yard, the calabash vine in the field, and the clay pit in the vicinity. Trade in these specific commodities was local.

A certain type of pottery was made in what is now El Salvador and is easily recognizable because of its glaze, it being the only glazed ware found anywhere in Central America. Pieces of this type have been found in Huehuetenango, Copan, Chichén Itzá, and as far distant as Vera Cruz and Jalisco (Thompson, 1929).

Maize was the staple, and in order to be converted into the maize cakes it had to be ground. The most favorable and efficient grinding stones were made of volcanic tufa. The Maya area was underlain by limestone. Ever so often we find that the local supply of rock had to serve as best it could.

Next comes clothing. It was the men who wore the gorgeous costumes; it was the priests who wore clothing and masks worthy of the gods they worshiped. Cotton was grown in most parts of the Maya country, and pieces of woven cotton of a stipulated size were

monetary units of trade. The Conquerors soon accepted this unit and claimed their tribute in this standard. The friars, voracious as of custom, tried to force the Indians to produce "bigger and better" cotton cloaks, meanwhile valuing them at the given standard.

Cotton garments were often woven with colored designs, and this indicates a trade in dyes. The loin clouts of the men were embroidered with the multicolored feathers of the toucan, the parrot, and the macaw, and the chiefs, nobles, and priests wore the gorgeous tail feathers of the quetzal (Nahuatl) or kukul (Maya) in their elaborate headgears. Now the macaw is scarce in Yucatán, and the quetzal is limited to a certain part of southern Mexico and Guatemala. The feathers of these birds could therefore be procured only by trade.

I can thank Charles Upson Clark for an extract from a manuscript, now in the Vatican library, by an unknown author, wherein it is said:

In the province of Verapaz they punish with death he who killed the bird with the rich plumes (*trogon resplendens*) because it is not found in other places, and these feathers were things of great value because they used them as money * * *

 (MS. Vatican Library).

Feathers were used for personal adornment, as was also jade and gold. The brilliant green tailfeathers of the "*trogon resplendens*", the vivid green of jade, were rare and therefore commanded a high price. The maize plant was green, the forest was green. All good as well as rare things were green, and therefore the Maya considered green a sacred color, attached special value to green things; just as the Spaniards, and we to this day, express wealth, abundance, and luxury in gold, and more frequently in gilt.

Jade was precious to the Maya. Landa (1864) mentions "this jade beads of fine stone of the kind the Indians used for money."

Even small slivers of jade were polished and perforated for suspension, and large pieces were carved in the shape of human faces, animals, or as the beautiful piece in the Middle American Research collection at Tulane University, shaped like a hand.

The American jade is chemically quite distinct from Chinese jade and the knowledge of the ancient jade mines has been lost. There is an indication that these mines were already lost or exhausted in Maya times. In caches or burials of the southern or oldest area we find comparatively large chunks of carved jade, whereas reworked pieces—i. e., larger objects that have been cut into smaller pieces and recarved—are often found in graves or with sacred offerings of later times, in Yucatán.

Gold was secondary in value and was brought in through trade from Oaxaca, Mexico, and the Chiriqui region in Panama. Gold figurines and bells of indisputable Chiriqui origin were found in the

Sacred Cenote at Chichén Itzá; and an exquisite gold pectoral, certainly of Nahuatl origin, was found in Guatemala and was acquired not long ago by the Department of Middle American Research from a New Orleans dealer.

Gold was foreign to the Maya area. Bernal Diaz mentions gold in the sand of the Uspanapa River, and both in this river as well as in the "de la Venta" the writer has washed very small quantities of gold. At Santa Fe, Tabasco, pockets of gold in the limestone were washed for a limited period within the last century, but gold in reasonable quantity was so scarce that it was regarded rather as an imported fancy than of actual established monetary value.

Free or virgin silver is so rare in the area that I have the greatest suspicion toward any silver object alleged to be of ancient manufacture.

Copper was more common. It is not found in the Maya area, but being of trade value among the neighboring nations, it is only natural to find it in the form of bells, hatchets, and other manufactured objects among the Maya. Copper bells of undeniably Nahuatl origin have been found not only in the Sacred Well at Chichén Itzá and likewise in great numbers in caves in Honduras, but also in the ruined cities of the present New Mexico, giving evidence of most widespread trade.

As copper tools have only a hardness of 3, against hardness of 7 for nephrite and jade chisels, it is obvious that copper tools were of little use.

Carving and cutting tools were made of obsidian, jadites, and flint. These materials were found within limited areas. The location of jadite is now unknown. Obsidian came chiefly from the mountains north of Coban and near Zacapa. There is an enormous deposit of flint nodules within the area of the Lake Yaxhá in Guatemala, east of the Mopan River, and north approximately to the present northern boundary of Guatemala with Mexico. Riding along the trail in 1928, and without any particular effort, the fourth Tulane expedition gathered a good collection of hammerstones, mallets, hatchets, and chisels, some of which were fine specimens and others only rejects, enough to show that the arms and tool industry of the Maya must have relied largely on this deposit.

Obsidian was used not only for knives and cutting edges for wooden swords, but also for ornaments and jewelry. Flint was mostly utilitarian, being employed for tools and weapons. Iron-and-sulphur-pyrite, the popular name of which is "fools' gold", is common in the limestone country of the Maya. It was used as inlay in incisor teeth as a matter of decoration; as mosaic mirrors; and when found in large nodules, it was cut and polished for solid mirrors. Vanity cases were apparently not unknown among Maya and Aztec.

This may be an appropriate moment to draw attention to the fact that European education classifies the advancement of man toward civilization through a group of "ages", i. e., the stone age, the bronze age, the iron age. After the last of these "ages", man was apparently civilized.

European man reached the iron age, where he was still divided into innumerable petty principalities, each fighting the other, all groping to achievement. Man of the American continent reached a far more complete civilization and a less complicated state of affairs using stone tools solely.

Iron tools were unknown in the American continent before the arrival of the Spanish hordes. If they had been known there, the world would have looked different today.

When we stand before any one of the hundreds of magnificent Maya temples, long abandoned, and now crumbling before the onslaught of time and vegetation, we must admire the fact that every stone was cut without metal tools, every stone and every basket of mortar was carried on a man's back. No beast of burden other than man was known to the Maya. Man was the beast of burden, and this beast was a slave. Slaves were a trade object.

The Maya were a civilized people, and as such they were divided into many classes, ranks, and castes. At the bottom of the division stood the slave, and even among the slaves there were distinctions.

He who defaulted a gambling debt at the ball game could be made a slave valued at the amount he had lost. He could not be resold for more than his debt, and he could be reinstated as a free man if he or his relatives paid the loss.

If a slave, man or woman, died within a certain time after sale, the seller was obliged to return a certain amount of the price to the buyer.⁸

Captives in war were made slaves, and their progeny was born in slavery. Thus we learn from Landa. The man who slept with a slave woman could be made a slave. Undoubtedly, it was slave labor which sweated to construct the religious structures. Certainly the traders had slaves to carry their loads of merchandise along the highways of Mayapan, the great "land of the royal turkey and the deer."

Nomadic peoples are dependent on the chase, civilized peoples live or die with their commerce.

In the foregoing I have enumerated some of the most important objects which the Maya traded, as well as their monetary units and their system of counting these units. I will now turn to the market-places where the merchandise was circulated.

⁸ Cogolludo: Lib. 4, Cap. 4, p. 292, ed. 1867.

There are many descriptions of the marketplaces of the Aztecs and these are probably typical of markets among the natives at the time of the Conquest. We have one description of a Maya market. It is hidden in the huge volumes of Oviedo (Lib. 32, Cap. 3 vol. 1): "they had very large markets or plazas, with many merchants and goods; both provisions and food, as well as of all the other things which are bought, sold, and exchanged among the natives."

A more detailed description is found in Ximenez' "Historia de Guatemala", tomo 1, p. 94, 1929 ed.

The rulers took great pains that there should be held great and celebrated and very rich fairs and markets, because at these come together many things; those who are in need of something will find it there and can be exchanged with those other necessary things: they held their fairs and exhibited what they had for sale close to the temples. The selling and buying is to exchange which is the most natural form of trade; they gave maize for black beans and black beans for cacao, exchanged salt for spices which were aji or chile . . . also they exchanged meat and game for other things to eat; they swapped cotton cloth for gold and for some hatchets of copper, and gold for emeralds, turquoises, and feathers. A judge presided over the market, to see that nobody was exploited. He appraised the prices and he knew of everything, which was presented at the market.

From accounts of the market in Tenochtitlan, the ancient capital of the Aztec empire, we know that judges presided over each marketplace, seeing to it that fair prices were asked and given, and it appears that a similar arrangement was common at the Maya markets.

An important factor in the movement of trade must have been the holy places such as Chichén Itzá, Cozumel, and others. At the religious festivals and on other occasions great crowds must have gathered from distant parts, not only to worship, but also to trade, just as we today see thousands of Maya descendants migrating every year to the fair at Esquipulas or the fiesta of San Antonio of Tila.

Many nations at many times had watched the North Star. Just as the Vikings about the year 1000 A. D. steered by this star on their voyages to Vineland, so the Maya travelers and merchants a thousand years earlier set their course over mountains and valleys after Shaman-Ek, the North Star, the god-protector of the travelers and traveling merchants. Incense was burned to him, and his image was venerated at wayside altars.

Traders followed the trails from town to town and from market to market. Cortés, when he tried to locate the rebellious Spaniards at Naco in Honduras under Cristobal de Olid, used maps drawn by traveling merchants on fiber paper, and also used traveling traders as guides.

From time to time his advance-guard would pick up these journeying traders, and his letter to the king often mentions these encounters (Cortés Letters, McNutt edition, 1908).

One of them, who was a native of Acalan, told me that he was a trader having its principal trade in the town of Nito, where those Spaniards lived, and that there was a large traffic carried on there by merchants from all parts of the country, and that his own people of Acalan lived in a quarter of their own, having as their chief a brother of Apaspolon, the lord of Acalan * * * (Vol. 2, p. 280).

That day they found two Indians, natives of Acalan, near a lake, who said that they were coming from Mazatlan where they had traded salt for cotton clothing, which indeed appeared to be true, for they were loaded with clothing * * * (Vol. 2, p. 265).

Landa (1864) tells us plainly that

The occupation to which they are most inclined is trading, carrying salt, clothing and slaves to the lands of Ulua and Tabasco, exchanging it for cacao and beads of stone which both were like money and with this money they could buy slaves and other beads, granting that they were fine and good, which the chiefs wore as jewelry during the feasts, and they had other beads made out of certain red shells which were valued as money and personal jewelry, and they brought them in their network bags.

In this connection the Motul dictionary (1929) informs us that the Maya word *tem* or *hotem* means "pocket" or "bag", in which the trading Indians carry the cacao beans which they spend. According to the Cortez Letters, vol. 2, pp. 263, 264:

Apaspolon, (the lord of Acalan) * * * is the richest trader and has the greatest shipping traffic of anybody. His commerce is very extensive and at Nito * * * there is an entire quarter peopled with his agents under command of one of his brothers. The chief article of merchandise of those provinces are cacao, cotton cloth, colors for dyeing and a kind of stain with which they smear their bodies to protect themselves against heat and cold; tar for lighting purposes, resin from pine for incensing their idols, slaves and certain red beads of shell which they greatly esteem for ornamenting their persons in their feasts and festivities; they trade in some gold which is mixed with copper and other alloys * * *

If we had traveled over the trade routes of the ancient Maya, we would have met innumerable caravans of slaves carrying merchandise, and led by merchants, carrying palm-leaf fans in their hands as a symbol of their occupation, and with a net-work bag containing their cacao-bean cash at their belt. Every evening the merchants would stop, preferably by a roadside altar dedicated to Shaman-Ek (Shaman: North; Ek: Star) and there they would offer incense and gifts to their guide and guardian, the North Star.

Sometimes the roads would be mere foot trails, but at other times they would be wide and well-paved roads, such as have been located in the region of Uxmal (Stephens, 1834) or the mighty paved high-

ways between Coba and Yaxuna, reported by several recent explorers (Saville, 1930).

It was not only in northern Yucatan that roads were found. Father Joseph Delgado traveled from Cahabon to Bacalar. On his way he was caught by "los enemigos Ingleses," the English pirate and renegade colony entrenched at Belize. They left the pious and pitiful padre in his underwear, and he groped along until he reached the town of Bacalar. Recounting his troubles he mentions that he: "followed roads through the swamps, which had been built in ancient times, and still were well preserved." (Delgado.)

The ruins of Palenque lie on a shelf, 300 feet above the alluvial plains of Tabasco. Back of the ruins rise spectacular limestone mountains. Below the ruins and parallel to the nearly perpendicular face of the ledge runs the Michol River, from west to east. From the mountains it is fed by a multitude of small streams, running from south to north, and entering the Michol at what is practically a right angle.

During my more than 3-months' stay at Palenque, in 1923, I made a rough survey of the ruins outside the area so splendidly surveyed in detail by Alfred Maudslay.

In the heart of the main part of the city is a bridge built in the shape of a "Maya arch" over a stream. During the survey I found several similar bridges, and in some cases I found huge stone buttresses on either side of a stream, indicating that a bridge of logs once had rested on these buttresses. Locating these bridges from the Michol made it easy to connect them on the ground. Slight excavation revealed the surface of a paved road connecting the bridges.

Thus we have evidence not only of a network of paved roads, but also of the fact that the highway department of the ancient Mayas built highways, bridged streams, and made swamps trafficable by roads raised above the swamps.

Trade moved over regular roads, crossing swamps and following mountain passes. The land trade was hauled on slaveback. Water trade was conducted in dug-out canoes, upon the rivers and along the coasts.

Because along said coast (probably the present British Honduras and Honduras) there is an extensive trade in said fruit cacao, which is used as money among the Indians, and which is very useful and precious, and richest and most highly estimated merchandise which they have, canoes go from Yucatán loaded with clothing and other goods to Ulua, and from there they return loaded with cacao * * * (Oviedo, 1851, 1853.)

I think that we can be allowed to state that for the water traffic there was even an established "lighthouse" service, because we read

that special signs were placed in the trees on the many islands at the Laguna de Terminos in order to tell the travelers which route to follow (Landa, 1864).

Over those trails traveled trade and treasures. Marble vases from the province of Ulua, raw or carved jade from its now unknown sources, the precious feathers of the quetzal bird; strangely beautiful vases with a metallic luster from that single place in the El Salvador of today where nature injected substances which when heated would produce a glaze of metallic sheen.

Copper bells, rings, and hatchets came over the trade routes from the distant country of the Aztec; gold images and pendants traveled from trader to trader until they reached Chichén Itzá in northern Yucatán, where they were prized enough to be offered to the gods—thrust into the Sacred Well for sacrifice, and retrieved in our times as links in the history of ancient trade of the Americas.

In that famous well of sacrifice were found small gold images of a type so distinct and characteristic that one is convinced that they came from the region of Panama. And in that same well were found copper bells which must have traveled south from the great city of the Aztec, Tenochtitlan, now Mexico City, and north to the greatest ruined city in our own territory, Pueblo Bonito, in New Mexico, abandoned many centuries ago.

Before closing, a few words must be given to business ethics among the Maya: Cogolludo (1867) tells us that in sales and contracts there was no written agreement, nor did they have letters of payment (*cartas de pago*: sales contracts) for security, but the contract was valid when the contracting parties drank together in public. This was in particular the custom in regard to the sale of slaves or earthen pots of cacao beans, and even today (Cogolludo wrote about 1655–56 and had access to many early records which have since been lost) these people say that they use this method between themselves when dealing in horses or cattle. The debtor never denied his debt, even though he might not repay it on time.

“They loaned and borrowed and paid courteously without usury”, so Landa (1864) informs us.

The Tabi documents—the originals of which are in the library of the Department of Middle American Research of Tulane University, where translations made by Ralph L. Roys are also available—speak in 1593 of a transaction in cacao beans. Evidently Francisco Quen advanced cacao beans on credit to Diego Huchim and Francisco Chim, who added some of their own capital in beans. Later there was an extended litigation before the Spanish courts. Those poor Indians, accustomed to conduct trade on word of honor, were

utterly confused when they were haled before our system of written contracts and mutual distrust so flagrantly a part of our system of commerce.

It is most obvious to see in the outcries of amazement which again and again occur in the eye-witness reports of Spanish Conquerors that they were astounded at two facts, (1) that anybody could have a monetary unit which was not based on gold and silver, and (2) that trade could be conducted without written contracts, signatures, and lawyers. To their point of view, as well as to our present-day viewpoint, a word of honor was a *beau geste* not to be trusted. This was a natural state of affairs to the Spanish Conquerors because they were soldiers of fortune, who believed only in the fortune they could carry in their pockets. A bullion-in-breeches idea. It must have been a terrific shock to the Maya to discover that they must change from their trade rule of trust to a rule of utter distrust.

Again I quote Oviedo, a soldier, who had no ax to grind. In his *Libr. 32*, chapter 2, vol. 3, p. 225, he says of gold: "One never pays to the owners of this (gold) a fair equivalent, but only gives them for one mark or two of gold a bell or a needle, or some pins, and thus and accordingly things of little value * * *."

This statement reveals clearly the contrast between the two systems of valuation, the two systems of monetary units. It contrasts the gold standard with the cacao-bean standard.

We know that the Spaniards were rejoiced at how they were cheating the Indians on a gold standard, and I am inclined to believe that the Indians were laughing at the Spaniards because they had acquired rare and precious things, and only paid them in gold.

In short, it is not the material that counts, but the value we give it.

BIBLIOGRAPHY

ALFARO, MELCHOR

1579. Map of the State of Tabasco. In *Relaciones de Yucatán*, vol. 2; and in DIAZ, BERNAL, True history of the conquest of New Spain, Maudslay edition.

CARDENAS, FRANCISCO

1643. *Relacion Historial Ecclesiastica de las Provincias de Yucatán*. Photostatic copy of MS. in British Museum.

CASAS, BARTOLOME DE LAS

1909 edition. *Apologetica Historia de las Indias*.

1875-6. *Historia de las Indias*, Madrid.

CHARLOT, JEAN

See THOMPSON, J. ERIC.

COGOLLUDO, DIEGO LOPEZ DE

1867-1868 edition. *Historia de Yucatán*.

COLUMBUS, BARTOLOMÉ

In HARRISSE, Henry, *Biblioteca Americana Vetustissima*, 1866 edition.

CORTÉS, HERNANDO

1908. McNutt edition. Letters.

DAVILA, ALONSO

In OVIEDO, *Historia General y Natural de Indias*.

DELGADO, FR. JOSEPH

MS. (Photostat in Middle American Research library). See also "Some Spanish *Entradas*, 1524-1695", by Doris Zemurray Stone, in *Middle American Papers*, Department of Middle American Research, Tulane University, 1932.

DIAZ, BERNAL

1632. *True History of the Conquest of New Spain*, Maudslay edition, Haklyut Soc., 1904.

ENCOMENDEROS DE MERIDA

1579. MS. in Sevilla, Archivo de las Indias, copied by Charles Upson Clark.

ENCOMENDERAS DE VALLADOLID

1581. MS. in Sevilla, Archivo de las Indias, copied by Charles Upson Clark.

HARRISSE, HENRY

See Columbus, Bartolomé.

LANDA, DIEGO DE

1864. *Relacion de las Cosas de Yucatán*. Genet, 1928-1929 edition.

LEON PINELO, ANTONIO DE

1639 edition. *Relacion . . . sobre la pacificación y población de las Provincias del Manché, i Lacandon, etc.*

MARTYR, PETER

Decades.

MOTUL DICTIONARY

1929. Juan Martínez Hernández edition.

MS. VATICAN LIBRARY

Reginensis Latinus, 659, fol. 160. *Apologetica historia sumaria*, quanto a las calidades, disposicion, descripcion, cielo y suelo destas tierras y condiciones, naturales, politicas, republicanas, manera de bivar, costumbres de la gente destas Indias Occidentales y Meridionales, cuyo imperio soberano pertenesce a los Reyes Católicos.

OVIEDO Y VALDES, GONZALO FERNANDEZ DE

1851-1855 editions. *Historia General y Natural de las Indias*.

POLLOCK, HARRY E. D.

See THOMPSON, J. ERIC.

RELACIONES DE YUCATAN

1898-1900. Col. documentos inéditos relativos al descubrimiento conquista y organización de las antiguas posesiones Españolas de ultramar, Tom. 11, 13.

ROYS, RALPH L.

Translations of Tabi documents in library of Department of Middle American Research, Tulane University.

SAVILLE, MARSHALL HOWARD

1920. *The goldsmith's art in ancient Mexico*. Mus. Amer. Ind., Heye Foundation, *Indian Notes and Monographs*, Miscellaneous no. 7.

1930. *Ancient causeways of Yucatán*. Mus. Amer. Ind., Heye Foundation, *Indian Notes*, vol. 7, no. 1.

STEPHENS, JOHN LLOYD

1843 edition. Incidents of travel in Yucatán.

SUAREZ DE PERALTA, JUAN

1878. Noticias Historicas de la Nueva España, Madrid.

THOMPSON, J. ERIC

1929. Comunicaciones y Comercio de los Antiguos Mayas. Anales de Sociedad de Geografia e Historia de Guatemala, Tomo 6, Sept.

THOMPSON, J. ERIC, POLLOCK, HARRY E. D., and CHARLOT, JEAN

1932. A preliminary study of the ruins of Coba, Quintana Roo, Mexico, Carnegie Institution of Washington.

XIMENEZ, FRANCISO

1929-1931 edition. Historia de la Provincia de San Vicente de Chiapa y Guatemala.

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